Space Shuttle Program

CR 134301

MSC-03309

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Engineering and Development Plan for Phase C/D

Volume I. Shuttle System

Contract NAS9-10960
DRL M010, DRL Line Item 14
DRD SE001M
SD 71-102-1
25 June 1971

(NASA-CR-134301) ENGINEERING AND DEVELOPMENT PLAN FOR PHASE C/D. VOLUME 1: SHUTTLE SYSTEM (North American Rockwell Corp.) 101 p

N74-76109

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SD 71-102-1
(MSC-03309)

25 June 1971

SPACE SHUTTLE
ENGINEERING AND DEVELOPMENT PLAN for Phase C/D
Volume I
Shuttle System

Approved by

B. Hello
Vice President and General Manager
Space Shuttle Program

Contract NAS9-10960
DRL M010, DRL Item 14
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Space Division • North American Rockwell 12214 LAKEWOOD BOULEVARD • DOWNEY, CALIFORNIA 90241

FOREWORD

This plan is one of a family of program plans that establish, as applicable, requirements and prospective implementation approaches for the conduct of Phase C (Design) and Phase D (Development and Operations) of the Space Shuttle Program. With the exception of the cost data, which appear in the Cost and Schedule Estimates Plan only, each plan has been prepared in accordance with the specific contract requirements described in the Contract NAS9-10960 Statement of Work, Paragraph 4.7 and Appendix A, Data Requirements. These plans are as follows:

Title	Volume	SD No.	MSC No.
Program Management Plan for Phase C/D	One volume	SD 71-101	MSC-03308
Engineering and Development Plan for Phase C/D	I. Shuttle System II. Orbiter System III. Booster System	SD 71-102-1 SD 71-102-2 SD 71-102-3	MSC-03309
Operations Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster	SD 71-103-1 SD 71-103-2 SD 71-103-3	MSC-03310
Facility Utilization and Manufacturing Plan for Phase C/D	I. Orbiter II. Booster	SD 71-104-1 SD 71-104-2	MSC-03311
Preliminary Test Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster IV. Shuttle Support Equipment V. Shuttle Software	SD 71-105-1 SD 71-105-2 SD 71-105-3 SD 71-105-4 SD 71-105-5	MSC-03312
Logistics and Maintenance Plan for Phase C/D	One volume	SD 71-106	MSC-03313
Program Cost and Schedule Estimates Plan for Phase C/D	One volume	SD 71-107	MSC-03314

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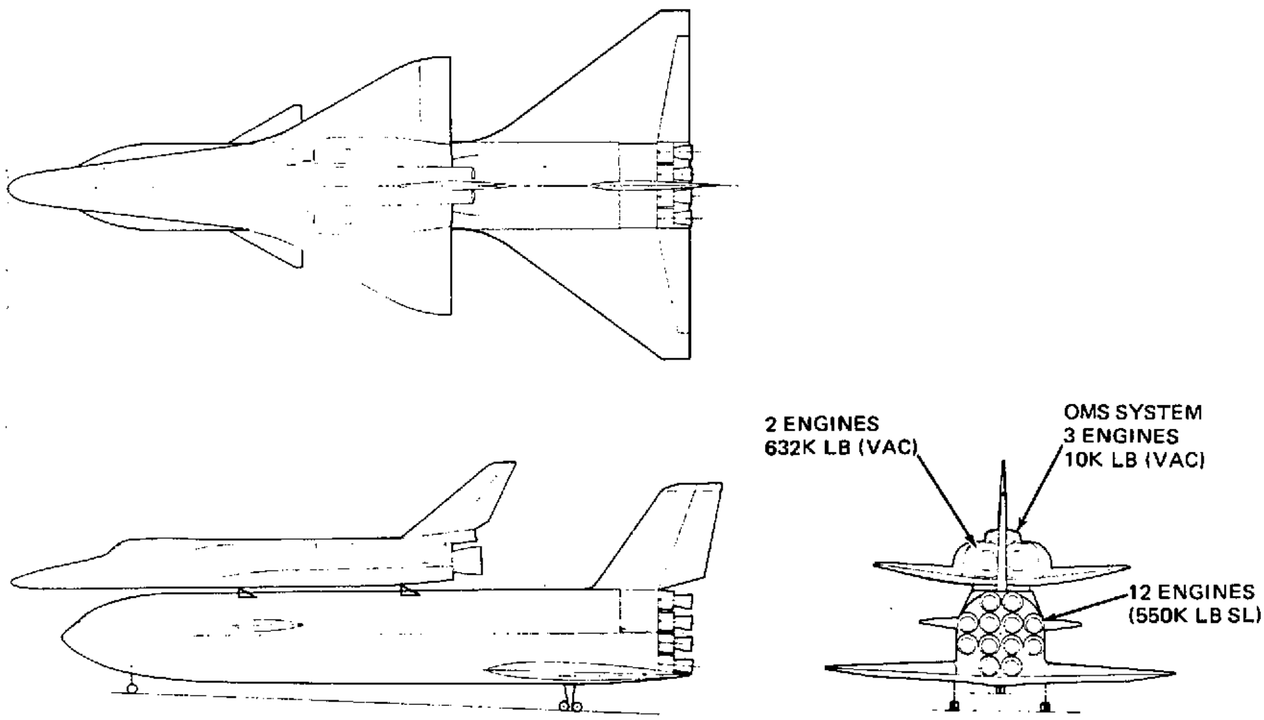
PREFACE

The objective of the Space Shuttle Program is to provide a low-cost space transportation system for placing and retrieving payloads in earth orbit. The first manned orbital flight is scheduled for April 1978. To achieve this goal, a reusable space shuttle system capable of a rapid turn-around, airline-type ground operation has been defined, satisfying as a minimum three basic missions: (1) 100-nautical-mile due-east circular orbit originating from a latitude of 28.5 degrees north, (2) a 55-degree inclination, 270-nautical mile earth orbit, and (3) a 100-nautical-mile south polar circular orbit.

To accomplish these missions, a two-stage launch vehicle (shown below) has been defined, which is capable of delivering into orbit one stage with its payload. Each stage is capable of atmospheric entry and return to a designated landing site. The vehicle features moderate acceleration levels, a shirtsleeve cabin environment and quick turnaround capability. Operational facilities and system support equipment complement the flight vehicle.



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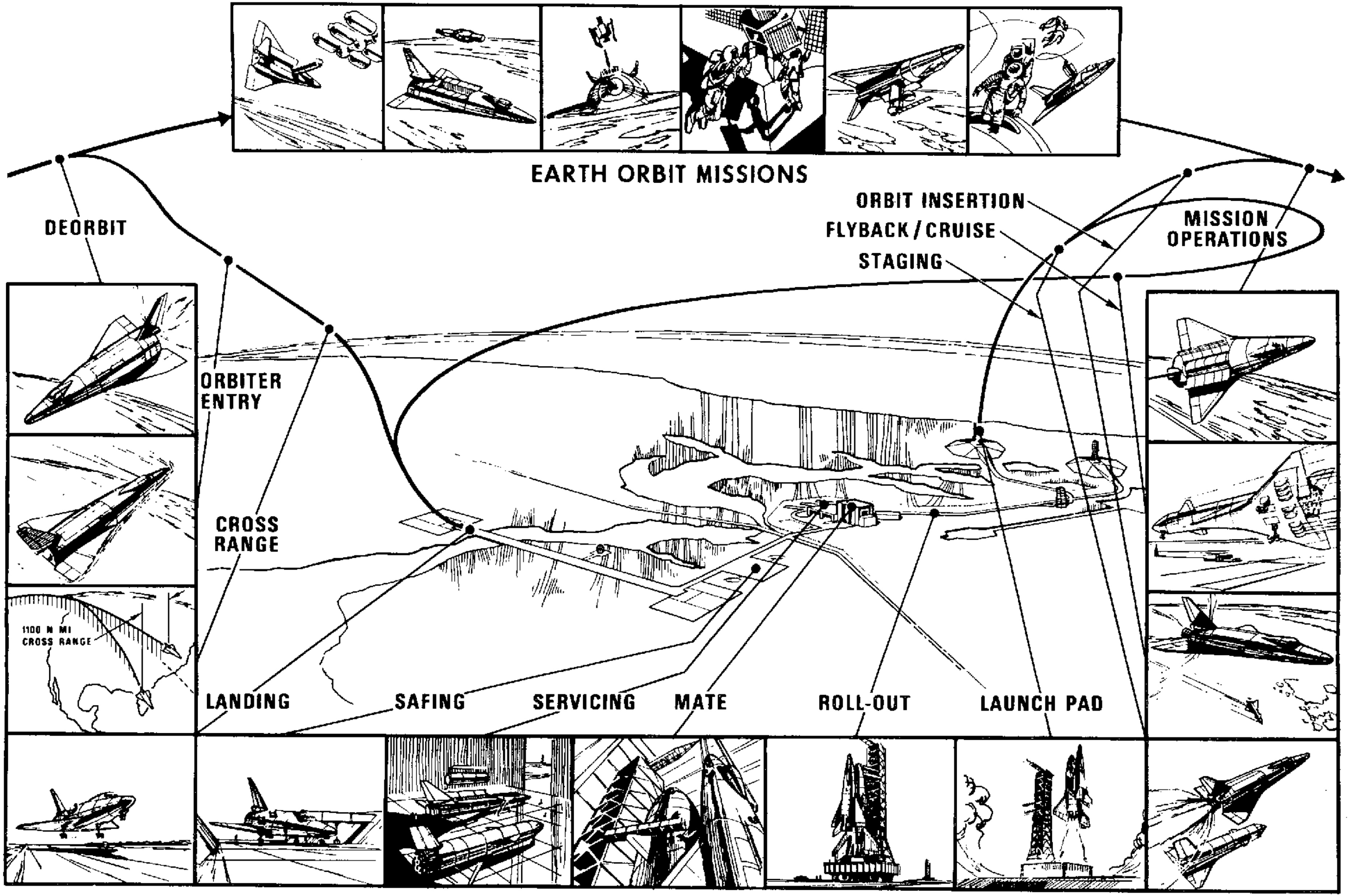
The booster and the orbiter are reusable delta-wing vehicles. The booster is equipped with 12 main rocket engines, an external heat shield to withstand the temperatures of boost and suborbital entry, and deployable airbreathing engines for cruising back to the launch site. The orbiter is equipped with two main rocket engines, orbital maneuvering rocket engines, an external thermal protection system to withstand the temperatures of boost and orbital entry, and deployable air-breathing engines installed for specific missions. The operations facility will provide for preflight readiness checkout, payload installation, and launch control, as well as primary landing sites and facilities for vehicle turnaround and necessary servicing. Shuttle support equipment includes all equipment required to check out, service, handle, and launch the flight vehicles.

The significant elements of these missions, as shown in the following figure, are ground operations, launch, and staging of the two vehicles. After staging, the first stage (booster) returns to the launch area while the second stage (orbiter) attains the prescribed insertion orbit after a series of orbital maneuvers. The second stage (orbiter) then delivers or retrieves its payload, enters the atmosphere, acquires the landing site, and completes the approach and landing. Safing operations are completed on each vehicle at the landing area preparatory to the turnaround cycle ground operations. Subsequent to payload installation in the orbiter, the orbiter is mated with the booster, and the mated system is made operationally ready and transported to the launch area for a new mission.



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Elements of Space Shuttle Operations

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of the Engineering and Development Plan is to define the requirements for the design, development, and certification of the space shuttle system. The shuttle system is segregated into major elements. Requirements and performance criteria for system elements as they pertain to development logic, engineering management, subsystem identification, engineering documentation/processes, certification test requirements and related disciplines (e.g., reliability, safety, quality assurance, maintainability, producibility, transportability, etc.) are discussed. The plan provides the framework for the design of the shuttle system during the Phase C/D period.

1.2 SCOPE

The Engineering and Development Plan is divided into three volumes, as follows:

Volume I:	Space Shuttle System
Volume II:	Orbiter System
Volume III:	Booster System

Volume I defines the engineering planning requirements for the total system development and summarizes the planning requirements for the development of the orbiter and booster systems. Performance criteria are specified, and design requirements for major systems are established based on the performance criteria and mission constraints. Design certification requirements are specified at the program level, and guidelines are established at the system level. Integration activities associated with shuttle system development are defined, and the approach required for interface control is specified.

Volumes II and III define the engineering planning requirements, in detail, for the development of the orbiter system and the booster system including support equipment. Orbiter/booster system performance criteria are specified, and design requirements are established based on performance criteria and mission constraints. Orbiter/booster engineering and development functions and design certification and integration requirements are identified at the system level. The combination of Volumes I and II defines the requirements for development of an orbiter system. The combination of Volumes I and III defines the requirements for development of the booster system.

2.0 SPACE SHUTTLE SYSTEM

2.1 MAJOR SYSTEM ELEMENTS

1. Orbiter System. Orbiter vehicle including payload provisions, a habitable payload module, and all unique support equipment excluding main engine

2. Booster System. Booster vehicle and all unique support equipment excluding main engine

3. Main Engine. Main boost rocket engine (power head), common to the orbiter and booster, and unique nozzels and related support equipment

4. Payload. Any or all cargo, or experiments designed for use in the orbiter payload bay and/or the habitable module including unique support equipment

5. Other Facilities and Support Equipment. Landing field and associated equipment, maintenance and refurbishment facilities, launch facility and associated equipment, major items of support equipment common to the two vehicles (e.g., fuel and oxidizer supply systems, ground power supplies and handling equipment, etc.)

2.2 MAJOR SYSTEM DEVELOPMENT LOGIC

Major system development logic is summarized in Figure 2-1. The engineering and development program is structured to support this logic with sufficient certification testing to verify integrity and performance capability for its intended use. This intended use will be horizontal individual booster and orbiter flight test, mated vertical flight test, and operational flight.

2.1.1 Horizontal Individual Booster and Orbiter Flight Test

The following systems and ancillary equipment will be provided for horizontal flight test:

1. Orbiter and booster vehicles and related support equipment required for horizontal flight. The vehicles and the critical

support equipment will be certified to the extent of verifying safety of flight and performance characteristics required for the modes being tested. Other support equipment will be certified to verify performance characteristics.

2. Simulated main engines will be provided with sufficient verification data to demonstrate their structural integrity.

2.2.2 Mated Vertical Flight Test

The following systems and ancillary equipment will be provided for vertical flight test:

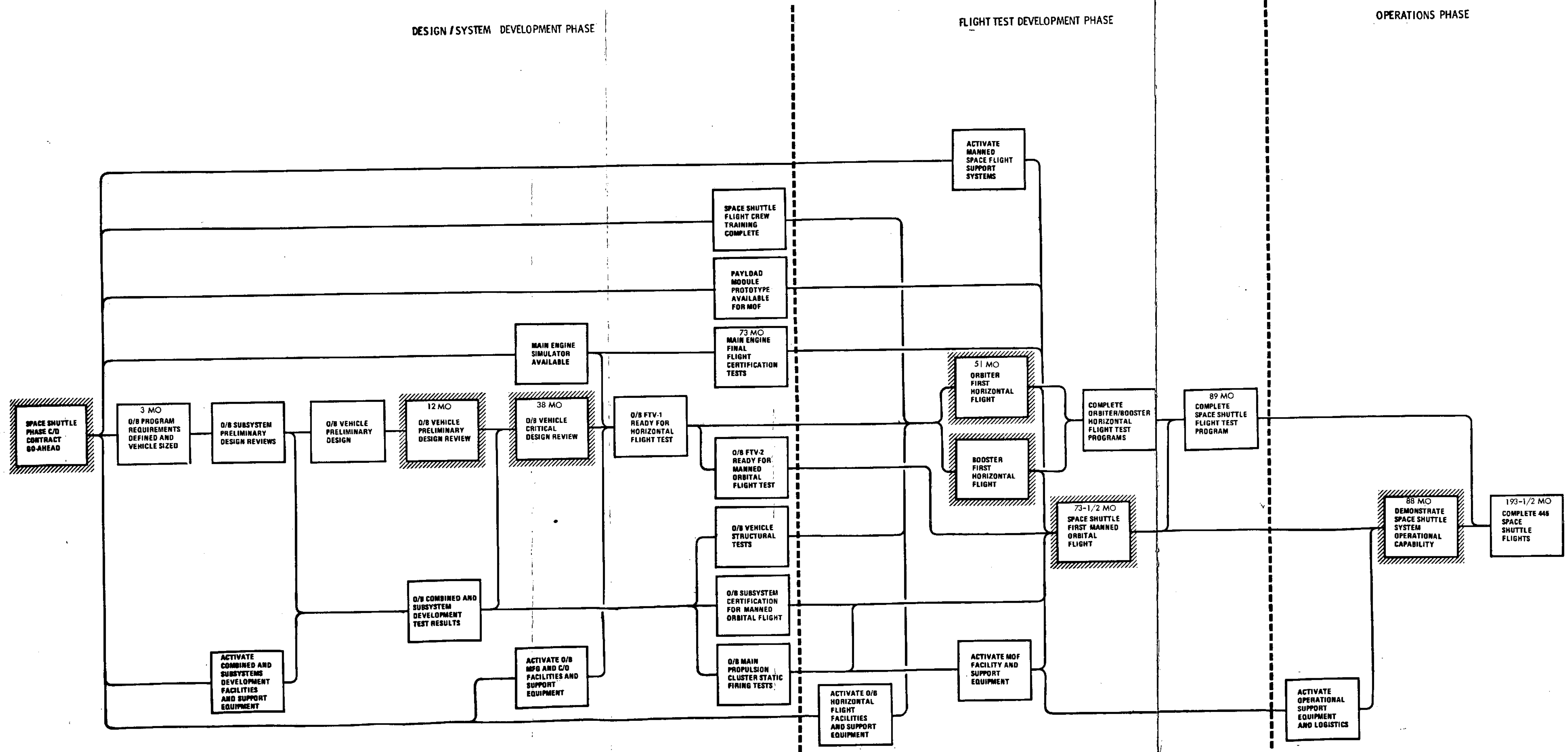
1. Orbiter and booster vehicle and all support equipment. The vehicles and the critical support equipment will be certified to verify all safety-of-flight and performance characteristics. Other support equipment will be certified to verify performance characteristics.

2. Main engines and all support equipment. The engines and the critical support equipment will be provided with sufficient certification data to verify all safety-of-flight and performance characteristics. Other support equipment will be provided with sufficient certification data to verify performance characteristics.

3. Other facilities and support equipment and a complete facility to support vertical launch will be provided and certified.

2.2.3 Operational Flight

All systems, support equipment, and facilities will be provided fully certified prior to operational use.



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A

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B

Figure 2-1. Space Shuttle System Development Logic Summary

2-3, 2-4 C

3.0 PERFORMANCE AND OPERATIONAL REQUIREMENTS

This section defines the major system level requirements established by NASA for the performance and design of the space shuttle system. Similar requirements that apply specifically to the orbiter system and the booster system are defined in either Volume II or Volume III of this plan as appropriate.

Additional performance, design, and functional requirements are defined in specifications, interface control documents, mission data and configuration data described in this section.

3.1 GENERAL TECHNICAL REQUIREMENTS

1. The flight vehicles will be designed to be reusable with a combined storage and operational service life of 10 years.

2. The operational facilities will be capable of supporting up to 75 flights per year and will accomplish prelaunch servicing and checkout within two hours.

3. The shuttle system will be designed to achieve maximum turn-around time of two weeks per flight vehicle.

4. The shuttle vehicles will be capable of all azimuth launch and feature rescue capability within 48 hours from a prelaunch standby status.

5. Landing characteristics and handling qualities of the flight vehicles will not require skills more demanding than those required for operational land-based aircraft.

6. The booster and orbiter will have the capability to land and take off on runways no longer than 10,000 feet at sea level under standard day conditions.

7. Visibility from the cockpits of the flight vehicles during landing will be comparable to high-performance aircraft standards.

8. Safe abort capability (intact abort) will be provided. This will be interpreted as:

   a. Crew/passenger escape prior to launch

   b. Safe orbiter/booster separation after launch but prior to nominal staging

   c. After separation for off-nominal conditions, the orbiter will be capable of performing a "once-around" orbit to land within the continental United States or abort to orbit.

   d. The orbiter and booster will provide for crew/passenger survival in the event of an emergency water landing.

   e. Ejection seats will be installed in both the booster and orbiter vehicles for use during the development flight test program.

3.2 REQUIREMENTS DOCUMENTATION

The space shuttle system will be designed to or be compatible with the following documents, which will be definitized prior to PDR during Phase C.

1. Space shuttle system specification including, as a minimum, the following interface control documents:

   a. Space shuttle vehicles to main propulsion engine

   b. Booster vehicle to orbiter vehicle

   c. Booster vehicle/orbiter vehicle/payload container to launch operations complex

   d. Orbiter vehicle and payload container to space station

   e. Booster vehicle/orbiter vehicle to maintenance and recovery operations complex

   f. Booster vehicle/orbiter vehicle to communications network

2. Development Contract End Item (CEI), Part I, specification for each major system element

3. Shuttle vehicle configuration documents to include profile and layout drawings, schematic block diagrams, mass properties data, aerodynamic, and other performance data

4. Design Reference Missions document including operational timeline for flight and ground operations

5. Mission traffic model describing each mission and frequency of missions

6. Baseline descriptions of existing facilities for supporting flight test and/or operational use

7. General test plan for the systems

8. Program Master Phasing Schedule

4.0 SYSTEM DEVELOPMENT REQUIREMENTS

This section defines the engineering and development activities required to design, develop, and test the space shuttle system.

4.1 ENGINEERING AND DEVELOPMENT LOGIC

The engineering and development logic for the space shuttle system is depicted in Figure 4-1. The logic establishes the order of engineering and development functions and related fabrication and review functions that are requisites to the development of the system. The selection and ordering of the functions represent the basic program flow. The logic for each system element and the interrelations between system elements are shown. The constraining relationship between elements are also discussed. Design reviews are discussed in the final paragraph of this section.

The initiating function for the design and development program is represnted by the definition of system performance, operational, and configuration requirements; design and test guidelines for the system and system elements; and definition of preliminary interface requirements for the main propulsion engine.

4.1.1 Preliminary Design

A flight vehicle synthesis will be required to resize the orbiter and booster and define basic shape and performance characteristics. This activity will establish performance requirements for the propulsion systems and the guidance navigation and control subsystems for the flight vehicles. Following this activity, preliminary design of the system elements can be initiated. Wind tunnel models of the flight vehicles will be fabricated from these preliminary designs.

Wind tunnel testing of the mated vehicle configuration will follow the synthesis activity and continue to provide the required aerothermodynamic loads and control data. Wind tunnel testing of the individual orbiter and booster vehicle configurations will provide similar data for the individual vehicle designs.

Concurrent with the flight vehicle preliminary design activities, the main engine development effort will be concentrated to providing final engine performance and interface data to the orbiter and booster contractors to permit finalizing vehicle configurations. These data will include thrust, specific impulse, mixture ratio, physical configuration, and mass properties data.

During this same period, all system element contractors will complete Part I Contract End Item Specifications. These specifications will establish the performance and design criteria for the perliminary design review configuration baseline. Additionally, NASA, supported by the orbiter contractor, will establish the preliminary design and interface requirements for payloads.

As a part of the preliminary design activity, the system element contractors will design and fabricate mockups of critical areas, design and fabricate breadboard test articles for critical flight subsystems, and fabricate and test sub-elements of the vehicle structure.

4.1.2 Detailed Design

Following the preliminary design reviews, the system element contractors will proceed with detailed design. During this period, the design and supporting analysis for the fabrication of development test articles, including system element components, subsystems, ground test articles, engineering mockups, and models, and flight test articles, will be produced.

The detail design phase will require a close coordination between all development activities to ensure a timely flow of data and development hardware. Significant items will be the development and delivery of main propulsion engine mockups and simulated engines to the booster and orbiter contractors for use during manufacturing and horizontal flight testing.

Payload requirements will be refined during this phase. Based on these requirements, the orbiter contractor will proceed with detail design of payload provisions including standard fittings and hold-down devices, a payload module simulator, a habitable payload module, and a payload deployment and retrieval system. The development of operational payloads and other payload modules will not be considered a part of the space shuttle system.

4.1.3 Support Equipment and Facilities

The support equipment and facility design functions will be phased incrementally to support horizontal and vertical flight tests. Preliminary design will also support fabrication of breadboard test articles. Detail design will support fabrication of certification test articles and operational elements.

The architectural and engineering (A&E) functions for the facilities will be phased to support activation of the sites for horizontal and vertical flight testing, in addition to activation for operational phases of the program.

4.1.4 Ground Testing

Fabrication of certification and structural test articles and flight test vehicles will be initiated following detail design. Certification tests will be performed in two phases; the first phase to demonstrate a capability for horizontal flight and the final phase to demonstrate a capability for mated vertical flight. Certification for mated vertical flight test will include the static firing of main engines in individual orbiter and booster test articles.

To support horizontal flight, the engine simulator will be verified during the structural tests. Engines will be provided to support the vehicle-engine static firing prior to mated vertical flight. Full flight certification will be completed prior to first vertical mated flight.

The testing of the payload simulators will be phased to support horizontal and vertical flight testing of the orbiter. The simulators will be tested to verify structural integrity prior to flight test. The operational module will be qualified to verify total operational capability and integrity prior to operation.

Certification testing of the support equipment will be in two phases to verify its adequacy for support of horizontal and vertical flight testing.

4.1.5 Flight Testing

Initial flight tests to be conducted on the orbiter and booster vehicle will be characterized by normal aircraft takeoff and landing (horizontal testing). These flight tests will be conducted individually on the respective vehicles. The horizontal flight test program will follow initial acceptance of the vehicle upon completion of manufacturing and verification of preflight checkout of the vehicles and procedures. The major contraints to initiation of this flight test phase are structural tests defined in Paragraph 4.1.4.

Following completion of the horizontal flight test program for both the orbiter and the booster, the first manned orbital flight test will be conducted. This phase of flight testing (referred to as vertical flight testing) will continue until the operational capabilities of the flight vehicle and all elements of the ground system have been demonstrated.

4.1.6 Design Reviews and Audits

Design reviews and audits will be performed at critical points throughout the program by the system contractors and will be monitored by NASA. The specific sequencing of the reviews will be as shown in Figure 4-1.

Successful completion of each review will be a prerequisite to proceeding to the next function. These reviews are briefly summarized below. For a detailed discussion of the program reviews, refer to the Program Management Plan.

1. Preliminary design reviews (PDR's) will be scheduled following completion of preliminary design to approve/accept the basic configuration.

2. Critical design reviews (CDR's) will follow breadboard and prototype testing and will occur at the approximate 95-percent detail design release to approve the design prior to fabrication of certification and flight equipment.

3. Site readiness reviews (SRR's) will be performed when test and operational site activation activities have been completed to support the intended program development phase. The reviews will verify that the facility and support equipment are operational and compatible with the test articles and the operations requirements.

4. Production configuration audit (PCA) will be performed to verify the configuration of the first deliverable production system element.

5. Flight readiness reviews (FRR's) will include a review of the configuration/fabrication history and checkout data for each vehicle prior to first horizontal flight and first vertical flight to verify the flight readiness status of the vehicle.

4.2 DEVELOPMENT REQUIREMENTS

Overall management of the space shuttle engineering and development function will be accomplished by NASA supported by major system element contractors. System element contractors will be responsible for engineering and development functions associated with each system element. Further definition of shuttle program management requirements are identified in the Program Management Plan.

4.2.1 NASA Responsibilities

Engineering Management

NASA will participate in the engineering activities to provide timely technical direction to the system element contractors. A summary of the NASA engineering responsibilities is presented below:

1. Chair all PDR's and CDR's.
2. Establish requirements for center/contractor support of PCA's and FRR's.
3. Validate all revisions to the contract WBS.
4. Based on the Program Master Schedule, determine subordinate system element technical milestones that support the overall schedule.
5. Coordinate with contractor(s) to establish cost target and budget distributions for the elements of the program.
6. Maintain an adequate staff at the contractor's main facility to ensure effective coordination of engineering efforts by both customer and contractors.
7. Establish working environments with development functions to implement mutually accepted interfaces with shuttle functions.
8. Arrange for timely provision of GFE to support development and qualification test programs.
9. Provide wind tunnel facilities or test data to support orbiter and booster design effort prior to vehicle subsystem PDR's and subsequent program development milestones.
10. Establish operational requirements and schedule and cost requirements; monitor and control development progress of the shuttle system.

Technical Requirements

NASA will establish the system and system element performance and design requirements (Section 3 of this document). These requirements will be updated as required based on the evaluation of operational requirements or the necessity to reapportion performance requirements between system elements.

Technical requirements will evolve from the system level and from analysis and design studies accomplished by the system element contractors. Integration activities associated with this effort are defined in Paragraph 4.4 of this plan.

System element contractors will perform the following tasks as directed by NASA to size the flight vehicles and definitize the vehicle configurations. These tasks include flight mechanics analysis, trajectory analysis, and wind tunnel testing and analysis of the mated shuttle vehicles.

Flight Mechanics and Trajectory Analysis. A flight mechanics program will be established to include, as a minimum, ascent performance and launch abort analysis. Ascent performance analysis will be conducted for the mated shuttle flight vehicle. Separation conditions for selected ascent trajectories will be defined. Detailed orbiter and booster parameter histories, mission ascent timelines, and control requirements will be generated. Studies will be conducted to define abort characteristics throughout the launch phase of the shuttle missions. Additional activities will include support to mission analysis and mission planning at the program level, establishment of data requirements and flight crew procedures, simulation and/or training programs, and definition of requirements for flight testing and analysis of test data.

Aerodynamics. Aerodynamic configuration design studies, flight performance characteristics, stability and control analysis, airloads analysis, and aerodynamic wind tunnel tests will be conducted.

Aerodynamic configuration design requirements and flight performance characteristics related to conditions existing during mated ascent will be defined.

Stability and control design criteria will be established. Airloads analyses for the mated configuration will be performed.

Integrated orbiter and booster rigid body airloads and distribution data will be defined. A wind tunnel program will be planned and conducted to provide data for the integrated orbiter and booster configurations. Aerodynamic requirements for flight test and aerodynamic analysis of flight test data will be provided.

Thermal Analysis. Aerodynamic heating analysis, thermal protection system (TPS) analysis, and thermal control system analysis will be conducted to define requirements for the design of the orbiter and booster TPS during mated ascent.

Definition of flow field models to support the aerodynamic heating environment and aerodynamic heating prediction modes will be provided.

4.2.2 System Element Requirements

This section summarizes the engineering and development requirements for the major elements of the shuttle system, and supplements the development logic depicted in Figure 4-1.

Detailed engineering and development requirements for the system element contractors are specified in either Volume II (orbiter), or Volume III (booster).

Orbiter/Booster System Development

The contractors will be required to provide the engineering efforts and materials necessary to design, develop, and certify all of the elements of the orbiter/booster systems. This includes vehicles, support equipment, and test articles. They will also be required to support flight test and operating requirements of the shuttle system.

The contractors will perform analyses and trade studies to establish configurations and detail design requirements; changes/modifications as required to the contract end item specifications will be identified. The contractors will produce the required procurement specifications and will support preparation of interface control documents as required. The contractors will develop and utilize breadboards, mockups, and test articles in individual and combined tests to certify system performance. Detailed design drawings, layouts, installation drawings and process specifications will be produced in adequate detail to allow the fabrication of the vehicles, sub-elements, and supporting equipment. A certification program will be developed and implemented to verify the capability of the vehicles and sub-elements to meet design requirements in the environments in which they operate. Engineering support will also be provided to all test programs involving multiple elements of the space shuttle system. Support will be provided to the development of checkout and operational procedures and post-flight evaluation. In addition, the orbiter contractor will be responsible for accomplishing design and development effort associated with the payload module simulator, habitable payload module, and the payload deployment and retrieval system.

Main Engine Development

The engineering functions of the main engine contractor will include those activities required to design, develop, and certify engines and associated support equipment in support of orbiter and booster test programs and subsequent operational phases. The contractor will also provide technical support to the vehicle contractors throughout the program test and operational phases.

Payload Development

Significant portions of the payload development function are generally anticipated to be outside the scope of the Space Shuttle Program. Individual payload modules and/or experiments will be constrained to satisfy uniform packaging requirements internal to the orbiter. To support the orbiter contractor in development of the orbiter system, the following functions must be performed:

1. Develop interface control documents that cover, as a minimum: weight, mechanical deployment and retrieval system, mechanical tie-down, electronic and electrical interfaces, cargo bay environment, flight crew access, ground operations, and orbital operations.

2. Review potential payload design characteristics and determine best set of standardized pallets and modules that satisfy the majority of candidates, which may include foreign corporations and government systems.

3. Design and develop recommended pallet and modules utilizing a building block approach as applicable.

4. Design and develop static test articles, mockups and models to support structural tests, and develop manipulating procedures and special requirements.

Facilities and Support Equipment Development

The orbiter and booster contractors will design and develop checkout and support equipment unique to the respective vehicles and assigned common usage items. Additional contractors may be selected to design and develop major ground system elements such as facilities and servicing equipment, launch support items, etc.

The contractors will perform analysis and trade studies relative to flight vehicle designs, test plans, maintenance plans, and operational concepts to establish support equipment and facility design requirements. Requirements analyses will be performed using the shuttle system specifications and flight vehicle CEI specifications to ensure an integrated support subsystem. The contractors will design, develop, test and certify the assigned ground system elements. Ground system engineering support will be provided by the contractors for the maintenance and operation of support equipment and facilities during all phases of development testing of the flight vehicles.

4.3 CERTIFICATION REQUIREMENTS

A certification program will be required in the engineering and development of the space shuttle system. The certification program will be comprised of development tests, qualification tests, acceptance tests, flight tests, facilities, and support equipment veritifaction. The detailed requirements contained in the Program Test Plan and summarized in this section are based on the following test philosophy and criteria.

4.3.1 Test Philosophy and Criteria

The test philosophy consists of a set of ground rules and criteria devised to (1) establish a base upon which to develop test logic and a test program that will meet the program objectives of low cost, flexibility, reliability, maintainability, and safety; (2) evaluate test requirements; and (3) assist in formulating design requirements as well as test, checkout, and operational requirements.

The test scope includes all test activities from tests for material properties and component selection through initial manned orbital flight of the first space shuttle and its subsequent operations.

The philosophy and criteria outlined allows maximum use of all test data to satisfy certification requirements and is aimed at establishing an integrated test program that will accomplish the basic objective of achieving adequate confidence at minimum cost.

1. The test philosophy and criteria established will apply to all of the prime items, including the orbiter and booster as single elements and mated, in addition to supporting systems unless otherwise noted.

2. Test requirements will be structured to identify and accumulate data for key component and subsystem parameters throughout all phases of testing. These data will be used in checkout procedures, development, trend establishment, and anomoly resolution.

3. Test equipment, checkout procedures, and data accumulation will be standardized where practical throughout all phases of testing and between all elements of the space shuttle system. The on-board checkout capability will be utilized to the maximum extent practicable.

4. The test approach will be based on requirements and past program experience to evolve integrated testing that will achieve a cost effective program to the maximum practical extent.

5. The baseline missions and timelines will be used in developing specifications requirements. All test requirements will be traceable to the CEI and/or system specifications. Mission requirement updating and changes must, in turn, be reflected in the appropriate specifications and documentation.

6. The maximum practical use of commonality will be employed for test methods and procedures, test equipment, support equipment, facilities, and operational techniques.

7. A test logic and constraint network will be used for tracking and control of the test program.

8. Special testing for reliability data and performance confidence will be by exception only; these data will be obtained by acquiring operating time data and failure trends throughout the development, qualification, acceptance flight, and operational phases of the program.

9. Repetitive testing will be minimized through the total test cycle subject to end-item delivery to the customer.

10. Maximum use will be made of existing contractor and Government test facilities where practical and cost effective.

4.3.2 Certification Testing

Verification that the engineering and development requirements have been met through certification testing and analysis will be required. The test categories for certification are development tests, qualification tests, acceptance test, checkout and flight tests. These tests will be performed on orbiter/booster subsystems, on orbiter/booster vehicles during ground and flight tests, and on facilities and support equipment as certification tests. The requirements for these tests are based on the test philosophy and criteria presented in Paragraph 4.3.1 of this volume as well as the preliminary Test Plan and are summarized in the following paragraphs.

Development Testing

The system element contractors will be required to perform the development testing necessary to achieve and verify the performance requirements of the system elements. Development tests are defined as those tests conducted to select and prove the feasibility of design concepts. Development testing is concerned with engineering evaluations of hardware and software for the purpose of acquiring engineering data, identifying sensitive parameters, and evaluating the development configuration performance. Development test activity will encompass materials, design feasibility, breadboard and wind tunnel testing, and major test articles.

1. All development requirements will be satisfied by the maximum use of analysis, supported by development tests or a combination of both.

2. Development of checkout and maintenance plans and procedures will be accomplished during subsystem development and verified along with operational procedures during the flight test program.

3. Structural testing on major test articles will verify a satisfactory design margin. To facilitate reuse of major structural test articles in subsequent test operations, destructive testing of major test articles will be minimized.

4. Early subsystem integration with software will be a key test requirement.

5. Testing will be structured to provide initial information on maintenance, i.e., replacement time and projected service life. Final replacement time and service life requirements will be established during the operational test phase.

6. When environmental testing is included in the development test program, the environmental levels will correspond to the most severe conditions anticipated for subsequent operational activity or testing.

7. When the commonality items have been identified, the development test program will encompass the most severe requirements of either the booster or the orbiter.

8. Development tests may serve as qualification tests in those certain cases where confidence is such that this action has a high probability of success and is cost effective. This applies to functional criticality II hardware only. The following additional criteria and rigors must be met.

   a. Predeclaration of intent to use test for qualification.

   b. Items to be in flight configuration; otherwise waiver required to substantiate difference as "no impact."

   c. Facility certified (calibrated).

   d. Test stands certified (calibrated).

   e. Inspection-contractor inspection on site, as necessary.

   f. Test requirement/approved.

   g. Procedure/tolerance.

   h. Prefunctional and successful postfunctional.

9. Overstress testing, when required, may be conducted at the completion of the development program utilizing the development hardware.

10. Development testing of subsystems will include verification of redundancy capability.

11. Data from EMI testing accomplished during the development program will be utilized for compiling information for subsequent subsystem EMI susceptibility assessment.

12. Acceptance tests, procedures, equipment, and test levels will be proven and verified for subsequent use on flight equipments during the development testing phase.

Qualification Testing

The system element contractors will be required to perform the development testing necessary to achieve and verify the performance requirements of the orbiter/booster system elements.

Qualification tests are defined as those tests conducted by system contractors on production articles to verify the functional performance of components and subsystems in specified environments to show compliance with specification requirements including any identified margins. Qualification will be based upon the "functional" criticality of the subsystem and will be performed only on hardware, which if failed, could result in loss of vehicle or crew life (Functional Criticality I). Functional Criticality II items may be qualified with management approval.

1. Qualification testing requirements may be waived when selected equipment has been previously qualified to the level required for the proposed shuttle application. In these cases, adequate substantiation of configuration, inspection, facility certification, etc., must be submitted with supporting rationale for approval of the waiver.

2. Qualification testing of components and/or subsystems will be accomplished on the highest practical level of assembly.

3. Hardware, failure of which could potentially result in loss of crew or vehicle (Criticality I), will receive a qualification test to the specified environments. Environments selected will be those that the hardware is expected to experience in its service life (ground and flight) plus the required design margin. The environment levels and durations will be the worst case condition and will demonstrate the design margins.

4. Qualification test levels must include verification of design safety factors.

5. Hardware, the failure of which would result in loss of primary or secondary mission objectives or launch cancellation, will be certified flightworthy by an accumulation of data from its test history during development, acceptance, off-limit, checkout, and flight test in lieu of rigorous qualification testing (Functional Criticality II).

6. The contractor will be responsible for maintaining documentation upon which certification and flight suitability is based.

7. Components that are to be subjected to qualification tests will first be subjected to the same acceptance tests applied to flight components.

8. Qualification of components, subsystems, and support equipment will be based on the functional criticality* of the system, as follows:

Criticality	Potential Effect of Failure	Required Tests
I	Loss of life of crew members (ground or flight). Also includes safety and hazard warning systems for primary operating systems whose failure has the potential of loss of crew members life. Loss of vehicle.	Qualification prior to system activation for first manned flight use.
II	Immediate (safe) mission flight termination or unscheduled termination at the next planned earth landing area. Loss of primary or secondary mission objectives. Launch scrub or delay	Development, acceptance, checkout, and flight testing
III	Other	Ground data accumulation or flight certification

Note: Functional criticality is the loss of function due to a single stress or environment where redundancy due to its packaging or location is negated. Determination requires failure mode and criticality effects analysis as well as knowledge of packaging and inboard profiles.

Acceptance Testing

The system element contractors will be required to conduct acceptance testing. Acceptance tests are defined as those tests conducted on deliverable flight and support equipment hardware to demonstrate that the product complies with specifications, is free from defects, and is capable of performing in conformance with stated contractual requirements. Acceptance tests begin with vendor tests and continue through demonstration at the time of vehicle delivery and acceptance by the customer.

Manufacturing "In Process" Test Components/Subassemblies

1. Acceptance tests at the component/subassembly level will provide the necessary quality/inspection and testing rigor to assure that functional pre-installation testing will not be required.

2. For environmental sensitive hardware, acceptance tests at the component/subassembly level must include specific environmental tests at a level commensurate with mission requirements, or to screen defects, whichever is greater. Criteria for selection of components and environments will be similar to those used on previous programs where proven effective.

3. Alternate or redundant path checkout will be a required component/subsystem feature.

Installed Subsystems

1. Subsystem level tests will include a demonstration of all alternate and/or redundant paths of operation, including malfunction switching logic, by exercising subroutines compatible with the on-board computer checkout and self-statusing capability.

2. Electromagnetic emission and/or susceptibility will be determined at the subassembly (black box) level. Subsystem EMI capability will be verified by performance checks during integrated checkout.

3. The on-board status and checkout capability, in conjunction with support equipment will be used to perform installed subsystem acceptance testing.

4. Retesting shall demonstrate the integrity of the rework areas only.

5. Certificable parts will be installed on the manufacturing line until such tests are successfully completed.

Flight Testing

The system element (orbiter/booster) contractors will be required to perform vehicle flight testing. Flight tests are defined as those development and certification tests to be conducted on the flight vehicles either as a single element (horizontal flight test) or in a mated configuration (vertical flight test). The test will demonstrate the functional and operational suitability of the flight vehicles and the integration of flight vehicles with ground and support systems, to perform this specified mission. Crew safety criteria for this flight test program will include crew escape provisions. Details will be provided by applicable trade studies and crew safety criteria documents.

Flight test instrumentation will be capable of being installed and removed without significantly impacting the on-board checkout system and data acquisition system or without causing extensive rework to put vehicle in final operational configuration. Incorporation of this temporary subsystem will be accomplished consistent with a requirement to minimize vehicle scar weight.

Horizontal Flight Test. Horizontal flight testing will be the post-acceptance flight checkout, limited to air-breathing engine operations, to demonstrate orbiter/booster horizontal flight, operational suitability, and handling qualities. This flight testing will be the responsibility of the orbiter/booster contractors.

1. All flight tests will be manned operations.
2. The first vehicle will be capable of being reconfigured for use as a fully operational flight vehicle. Subsequent orbiter and booster vehicles will be fully configured and utilized to demonstrate nominal operations.
3. The initial flight test program will demonstrate aspects that will include but not be limited to the following:
   a. Ferry capability
   b. Landing capability of both vehicles including the orbiter with and without air-breathing engines (the air-breathing engine system (ABES) will demonstrate one-engine-out performance and in-flight restart for both orbiter/booster)
   c. Maintainability and ground turnaround time
   d. Subsystem operation and performance

Vertical Flight Test. Vertical flight testing will be the responsibility of NASA supported by the orbiter/booster contractors. It will include launch, separation, entry, transition, and landing of the booster and launch, separation, orbit, entry, transition, and landing of the orbiter.

1. The first mated vehicle orbital flight test will be an open-ended mission.
2. Final flight test orbital launches will demonstrate the capability to meet interface requirements with other program elements.

3. Main-engine-out capability will not be included as a part of the flight test program but will be demonstrated during the ground test propulsion test program.

Facilities

The facilities will be subjected to test and evaluation by the contractors to ascertain that they satisfy the criteria for intended use. Each facility and installed support equipment will be subjected to verification tests prior to its first use and periodically thereafter.

1. The initial activation phase will be accomplished to verify physical and functional compatibility of the facility and support equipment systems with the orbiter/booster interfaces.

2. Facility systems utilized in support of orbiter/booster maintenance and operations will require revalidation at periodic intervals in accordance with established calibration, proof load, and maintenance standards.

3. Support equipment systems at each test and operational site will require periodic revalidation in accordance with established frequencies. Use of the support equipment system with an orbiter/booster vehicle will constitute validation and will start a new cycle.

Support Equipment

Support equipment includes those nonflight end-item models and associated software that service and checkout the space shuttle for flight or perform support for maintenance activities. Certification tests will be performed for the development, qualification and acceptance consistent with flight hardware criticality categories. The basic guidelines are as follows:

1. Commonality of test procedures and techniques will be maximized for all common use equipment identified.

2. The earliest practical cost-effective use of deliverable support equipment will be implemented to support the program including airborne equipment development tests.

3. All support equipment or appropriate parts thereof will be subjected to an acceptance functional test to demonstrate that the individual unit of equipment satisfies the requirements of the end-item model specification.

4. An integrated test of the support equipment and facility at each major test and operational site will be performed to demonstrate operational suitability and interface compatibility.

5. High-cost operational media testing will be deferred to the integrated test.

6. Support equipment end items acceptance/operational test and checkout requirements will normally be structured to assure suitability to perform intended purpose rather than to verify inherent capability.

7. Acceptance test will demonstrate operability of redundant operating modes and safety devices.

8. The design integrity of all first article support equipment performing a structural function will be verified by a design proof-loading sequence that encompasses significant worst case loading. All structural-type support equipment will be subjected to a periodic specified proof-load test program after being placed in service.

9. Acceptance tests will not be conducted specifically to verify EMI susceptability.

10. Acceptance tests will not be conducted specifically for reliability, human factors, maintainability, or life-cycle purposes. Their parameters will, however, be considered in design.

Test Tolerance

1. A pass-fail criterion or acceptability tolerance (including margins of safety) based on the test requirements will be specified by the system contractors for all tests.

2. The tolerance band of acceptance about the expected or specified nominal test level will be based upon instrumentation accuracy, facility/support equipment-stimuli tolerance, test specimen tolerance stack-up, or expected variation from specimen to specimen depending on the manufacturing tolerance, external environment (pressure, temperature, humidity, etc.), test influence variations, and other parameters as may be deemed necessary.

3. The tolerance band will be most stringent (narrow) at the manufacturer's component or subsystem acceptance to assure a good screen for workmanship. The tolerance band will be expanded for vehicle checkout and flight testing in consonance with the apportionment of the hardware's contribution to total system tolerance limits. Subsequently, the tolerance limits will be expanded, based on flight test and other use experience, for the operational phase of the vehicle.

4. Standardization of procedures and equipment for checking hardware acceptability will be maximized throughout the test and operational cycle.

4.4 INTEGRATION REQUIREMENTS

An overall summary of the areas that require integration with a brief statement of the integration activities required for each area is presented below and in the Program Management Plan. The requirements for each activity are defined in the appropriate volume of the Engineering and Development Plan (i.e., herein for system-related activities, Volume II for orbiter-related activities, and Volume III for booster-related activities).

4.4.1 Integration Areas/Activities Summary

The following subsections summarize the integration activities for all areas of the shuttle system.

Shuttle System

1. Control the system specification; allocate requirements to appropriate CEI specification.

2. Perform vehicle synthesis/sizing analysis to assess impact of proposed changes and allocate requirements to the appropriate system element.

3. Control the system level ICD's; Chair Interface Control Working Group to assess changes/problems.

4. Prepare and control launch constraints document.

5. Conduct overall planning for initial flight operations.

6. Assess shuttle system to assure flight readiness.

7. Accomplish mission planning; establish vehicle utilization, configuration, requirements, and payloads.

8. Establish requirements to achieve uniformity/integration for safety, reliability, maintainability and quality assurance.

9. Perform periodic reviews to assess program progress, specifically in relation to cost, schedule, and technical performance.

10. Participate in all shuttle system program reviews, e.g., PDR, CDR, FRR, etc.

Orbiter/Booster Systems

1. Assure integration of all internal vehicle systems and their compatibility with the vehicle CEI specification.

2. Verify compatibility between system specification and vehicle CEI specifications.

3. Prepare main engine/orbiter and main engine/booster ICD's.

Orbiter or Booster System with Support Equipment and Facilities

1. Define and control orbiter/booster SE requirements.

2. Define facility requirements for compatibility to identified SE.

3. Prepare ICD's for vehicle/facility, and SE facility interfaces.

4. Identify SE requirements peculiar to orbiter/booster for inclusion at all potential operational sites.

Orbiter System SE with Booster System SE and Combination with Facilities

1. Integration of orbiter/booster SE requirements for operational site.

2. Plan SE/facility complex - design and performance consistent with time limitations.

3. Prepare and negotiate and control SE/facility complex requirements.

Orbiter System with Other Space Program Elements

Prepare and negotiate and control interface documentation.

Orbiter System with TDRS and Other Orbital Communication/Navigation Aids

1. Define orbiter requirements.

2. Prepare required interface documentation.

Orbiter System with Payload

1. Establish and control orbiter requirements to accommodate payload spectrum.

2. Establish and control payload requirements which evolve from/during orbiter development.

3. Prepare and negotiate, control required interface documentation.

Shuttle Vehicle Ground and Flight Test Programs

1. Define and establish test objectives for the system and its elements. Test objectives will be established on a mission basis.

2. Define specific element requirements for each mission in support of test plan and test objectives.

4.4.2 Integration Areas and Activities (System Level)

The following paragraphs define in detail the shuttle system related integration activities required during the Phase C/D development period. Integration activities associated uniquely with either the orbiter or booster are defined in Volumes II or III of the Engineering and Development Plan as appropriate.

Shuttle System

1. Prepare and control the shuttle system specification that establishes total vehicle requirements and allocates these requirements to each element. Prepare guidelines for preparation of element CEI specifications to assure traceability of system level requirements. Establish and operate a change control system for the shuttle system and element CEI specifications.

2. Perform synthesis/sizing analyses as required to establish allocation of requirements to each element of the shuttle system.

3. Prepare, negotiate, and control physical and functional ICD's between elements of NASA and the shuttle system (e.g., space station, MSFN, etc.) and between elements of the shuttle system (e.g., orbiter/booster-ground, booster/orbiter, etc.). Establish and chair an interface control working group (ICWG). The ICWG shall include representatives from each system developer (contractors and NASA centers). The group will assure early and rapid identification and resolution of problems involving compatibility between elements of the shuttle system.

4. Prepare, negotiate, and control launch and flight constraint documents for the shuttle system for each reference mission type. This includes definition of backup and alternative procedures for contingency situations.

5. Overall planning of initial mated flight operations commencing with receipt of the individual flight vehicles at the test site through mating, launch, mission performance, and recovery until shuttle vehicle operational status is achieved. The function includes development of specific sequencing, timelines, and detailed scheduling through the SE/facility complex along with assignment of task responsibilities with appropriate definition of interfacing requirements.

6. Assessment of flight readiness of the shuttle system for initial mated mission. This function includes definition of all test/analytical constraints within the development program (of the system and each element) and determination that all constraints have been satisfied. This includes design certification through acceptance testing, preflight checkout and inspection, and equivalent assessment of SE/facility complex as to its readiness to support the flight test.

7. Missions planning to establish vehicle utilization, special configuration requirements for accommodation of specific payloads, scheduling of SE/facility complex utilization and assignment of payloads to specific vehicles to minimize modifications between flights. This function accomplishes blending of all missions within specific time span and allocates vehicle/vehicle elements for their accomplishment.

8. Definition of vehicle/element requirements (propellant loads, timelines, constraints, etc.) for each mission. Function includes preparation, publication, and control of documentation defining requirements for each system element along with the process and operational documentation from the time of mating through launch and mission completion. The function customizes those general mission-oriented requirements defined in items 1, 4 and 5 above to fit the specific objectives of the mission to be flown.

9. Establish requirements and guidelines to assure an integrated approach for achieving quality, reliability, safety, and maintainability in the shuttle system.

10. Perform periodic evaluations of the progress of the technical program accomplishments versus cost and schedule performance. These evaluations will include applicable recommendations for replanning the technical program, identification of programming problems requiring corrective action, and implementation of program problem studies and changes.

Orbiter SE with Booster SE and Combination with Facilities

This subject is discussed for locations at which both vehicles are tested or operated individually or mated.

1. Integration of orbiter and booster SE requirements for operational site.

2. Plan SE/facility complex and its utilization to minimize duplication of SE end items but assure capability to perform operational cycle within prescribed time limits.

3. Prepare, negotiate, and control SE/facility complex requirements document which defines quantities, types, and acquisition schedules for SE and facilities and defines design/development/acquisition responsibilities for all SE end items.

Orbiter with Other Space Program Elements

1. Prepare, negotiate, and control physical and functional ICD's between the orbiter and space station and between orbiter and any other orbiting element with which interfacing is required for purposes of cargo or passenger transfer.

2. Establish a system for generating equivalent interface documentation for any other orbiting object the orbiter may be required to service during the course of the operational program. Establish generalized requirements for potential imposition on the orbiter design for this family of potential tasks (missions). Evaluate such potential requirements and disposition in terms of (1) accommodation in initial orbiter design, (2) accommodation through kit preparation, (3) delay action until requirements become specific.

Orbiter with Payload

1. Establish requirements to be imposed on the orbiter design to accommodate the expected payload spectrum. Determine the method for imposition of each requirement in terms of either built-in orbiter capability or standardized kits with appropriate installation provisions as "scar" design in orbiter. This function includes physical (mounting, weight, center-of-gravity, location, deployment, servicing) requirements as well as functional (monitoring, checkout) requirements.

2. Establish general requirements to be imposed on all payloads to be carried by the orbiter. This includes weight, size, shape, center-of-gravity location and stability, environmental tolerance, etc.

3. Prepare, negotiate and control physical and functional ICD's for the orbiter interface with a generalized payload. Establish and implement a system for preparation, negotiation, and control of specific interface requirements for specific payloads not fitting within the generalized ICD. Establish this system in consonance with required lead times for incorporation of additional support capabilities within the orbiter.

Shuttle Vehicle Ground and Flight Test Programs

Test objectives for the shuttle system and its elements for each development mission to be flown along with special configuration requirements and/or system/element constraints are to be defined. Accomplishment of this function provides basis for detail planning and establishment of detail requirements for each developmental mission.

4.5 COMMONALITY REQUIREMENTS

A key consideration in development planning of the space shuttle system is the possible reduction of overall program costs through implementation of commonality. Commonality refers to those items that can be developed, procured, and/or performed in a common manner during Phase C/D activity and includes not only hardware, materials, and software common to the orbiter, booster, or associated ground systems, but also encompasses facilities, procedures, and services (training, logistics, etc.) that apply to common hardware items.

Consistent with system requirements and cost objectives, the contractors will provide and implement the management processes necessary to achieve and maintain commonality during Phase C/D, perform the coordination necessary for identification of additional commonality candidates and make recommendations, including presentation of supporting data, to NASA for such additional commonality candidates. In addition, the contractors shall assist NASA in establishing a change control system that assures proper evaluation of proposed changes to common items prior to presentation of change recommendations to NASA for final disposition. The contractors will participate in a Commonality Working Group (NASA) as discussed in the Program Management Plan.

The contractors will be responsible for common items and/or systems as either the development contractor or the using contractor as assigned by NASA in the CEI specifications. Responsibilities for each category are listed below.

1. Development Contractor Responsibility

   a. Develop vehicle unique and obtain total (orbiter/booster) requirements

   b. Prepare procurement specifications, drawings, quality/manufacturing requirements

   c. Select vendor

   d. Direct the design/development program

   e. Direct and/or perform the certification test program

   f. Approve certification tests

   g. Procure hardware for either the orbiter or booster as appropriate

   h. Certify hardware acceptability

   i. Direct failure analysis/corrective action

j. Coordinate/approve change control activity

k. Establish provisions for maintenance, repair, and modification at joint operating sites

l. Manage/conduct the quality assurance program (maintain complete historical documentation file)

2. Using Contractor Responsibility

a. Develop and provide vehicle unique requirements (ICD format)

b. Review and approve procurement specification, drawings, quality/manufacturing requirements prepared by the development contractor

c. Concur in vendor selection

d. Monitor design/development; approve design

e. Monitor certification tests

f. Approve certification tests

g. Procure hardware for either the orbiter or booster as appropriate

h. Certify hardware acceptability

i. Request and monitor failure analysis/corrective action

j. Request and approve change control activity

k. Request maintenance and modification provisions.

4.5.1 Commonality Identification

A list of commonality candidates (subsystems and components) has been developed and is included as an appendix to Volume I of the Engineering and Development Plan. No attempt has been made to assign commonality and/or development responsibility. During contractual negotiations for Phase C/D, the selected prime (orbiter/booster) contractors will participate as noted, under NASA direction, in a working group to finalize the commonality plan/approach to be used during system development.

4.5.2 Common Item Specifications

When assigned development responsibility, the contractors will assist NASA in collecting and integrating requirements for common items. This task includes initial preparation of the requirement specifications, evaluation of changing shuttle system or element requirements which could affect common items, coordination of changes resulting from these analyses, obtaining NASA approval, and publication of changes as required.

5.0 GENERAL ENGINEERING AND DESIGN REQUIREMENTS

The design and development of the system elements will be governed by system design criteria and executed by basic engineering processes as specified in this section. Design verification will be achieved based on the test philosophy and criteria in Section 4. 3 of this volume. The responsible disciplines will participate in the contractor's activities to assist in requirements definition and participate in design reviews to ensure these criteria are incorporated in the design. The scopes of the system design criteria, the required basic engineering processes, and the design verification requirements are described in the following paragraphs.

5. 1 SYSTEM DESIGN CRITERIA

The contractors will provide system design criteria for system safety, reliability, maintainability, electromagnetic compatibility (EMC), standardization, human factors, producibility, and transportability in the engineering and development of the system elements. The contractors will establish plans, controls, and implementing procedures to meet the criteria defined. The effort will be integrated at the system level by the establishment, definition, and implementation of guidelines, scope of effort, areas of application, methods of data interchange, and methods of verification. The level and degree to which the design criteria are applied will be consistent with the safety, performance, and mission requirements of the program. The degree of application will be selective and will be determined by a study and assessment of the criticality categories, risk factors, and systems/cost effectiveness factors involved.

The following are more detailed requirements for the implementation and integration of the system design criteria and design characteristics into the system elements.

5. 1. 1 <u>System Safety</u>

The contractors will establish and implement a system safety plan to cover all phases of the Phase C/D program. The program will be structured to assure that safety features are designed into the vehicle and the supporting equipment, and will be coordinated with the industrial safety program. The program will consist of analysis, review of designs, investigation of accidents or incidents, and implementation of corrective action as required. The requirements for the system safety program are defined in Appendix C of the Program Management Plan.

Safety Criteria and Requirements

The contractors will establish safety criteria and requirements to govern the design. These criteria will be updated as experience indicates the need.

Special consideration will be given to abort procedures and capabilities, and operating and maintenance procedures for all emergencies.

Safety Analysis

The failure mode and effects analyses and the single-point failure analysis will be reviewed for safety considerations. All designs will be analyzed to assure that there are no potential catastrophic failures such as fire, explosion, or hazardous outgassing. Crew interfaces will be analyzed to verify that inadvertent or accidental actions will not result in hazardous conditions.

Procedure Review

Selected procedures shall be reviewed for adequacy to assure the safety of personnel and equipment and to assure that emergency procedures for hazardous tests and operations are defined.

Investigation of Incidents

The capability will be provided to investigate incidents and accidents. Causes will be determined and corrective actions defined and implemented as required.

5.1.2 Reliability

The contractors will develop a planned integrated approach to achieving optimum operational reliability compatible with the Shuttle Program objectives. Reliability will be achieved in the design of the system by imposing reliability design criteria and integrating design analysis and problem resolution tasks early in the design phase, and monitoring the conformance of these efforts to meet shuttle requirements. These requirements, which are defined (along with their depth of application) in Appendix A of the Program Management Plan, will be met by the successful accomplishment of the following activities:

1. Reliability management program (including subcontractor control)

2. Criteria establishment/assurance

3. Reliability analyses/assessments

4. Failure mode effects analyses and single-failure point summary

5. Design specification controls

6. Design/end item review program

7. Parts control program; materials control program

8. Problem reporting, analysis and corrective action program

9. Product certification program

5.1.3 Maintainability

The contractors will establish a maintainability program encompassing the Phase C/D engineering and development program. The program will include technical design requirements for subsystems, definition of design criteria, a support and monitoring technique to assure that the designs are meeting the criteria and the technical requirements, and a procedure to verify compliance with technical requirements. The program maintainability requirements are discussed in detail in the Shuttle Logistics and Maintenance Plan.

Technical Design Requirements

The contractors will perform analysis to establish task times for scheduled and unscheduled maintenance. The analysis will consider the expected frequency of maintenance and the maintenance time allowable. These will be established as design requirements for each subsystem and the vehicle as a whole.

Design Criteria

Qualitative design criteria will be established and made available to the designers. These criteria will be followed to the extent possible. Criteria will include such items as:

1. Accessibility

2. Provision of adequate working space

3. Features to preclude maintenance errors

4. Capability to perform tasks simultaneously

5. Need for special tools or equipment

6. Capability of fault isolation with minimum equipment

7. Minimization of servicing and periodic maintenance

During the design phase, the contractors will analyze the design to predict the maintenance task times to assure compliance with requirements.

Verification

The contractors will establish procedures to verify that the allowable vehicle maintenance task times have been met. This verification may consist of a combination of analysis and tests to achieve the verification in the most cost-effective manner.

5.1.4 Producibility

The contractor will address producibility as a method for achieving cost-effective design and the necessary procedures for its implementation. This will include but not be limited to reviews and inputs during conceptual design, design surveillance and consultation during layouts and detail design prior to release of production drawings, generation of design fabrication data, and coordination between design engineering and manufacturing during fabrication.

5.1.5 Electromagnetic Compatibility

The contractors will establish an electromagnetic control (EMC) program to govern all phases of the Phase C/D development program. The program will be defined in an EMC plan prepared by the contractors and will be submitted to NASA for review. This plan will be consistent with the requirements that are established at an integrated shuttle system level.

EMC Program

The EMC program will include the following:

1. The method to be employed by subcontractors in implementing EMC programs, including design practices to be followed, technical electromagnetic interference (EMI) requirements, and verification requirements.

2. Design practices at the component subsystem and vehicle levels. This will include grounding and bonding practices, shielding requirements, and wiring techniques including placement of wires within bundles.

Power Quality Requirements

Power quality requirements will define the quality of power which vehicle equipment and components must be designed to operate with as well as the quality that must be supplied by the electrical power generation system and the electrical power and distribution system. DC power quality requirements will include the limits on long-term voltage variations and time and amplitude limits for transients and ripple voltage.

AC power quality requirements will include limits on long-term voltage and frequency variations, time and amplitude limits for transients, limits on variation between phases, and modulation limits as a function of frequency.

Conducted and Radiated Generation and Susceptibility Requirements

Design goals will be established at the equipment levels. These goals will include (1) the levels of conducted and radiated interference environment within which the equipment must operate (susceptibility), and (2) the maximum levels of conducted and radiated interference which the equipments may generate. The above quantities will be defined in quantitative levels as a function of frequency.

Equipment Test

All equipment and subsections individually and/or collectively will be tested to verify compliance with the design goals. The results of all EMI tests will be analyzed to verify compliance with design goals or to define specific areas where outages exist. If conflicts exist, design fixes will be implemented, as required, to either reduce susceptibility or generation.

5.1.6 Standardization

The contractors will minimize costs through control of design practices, fabrication processes, parts, devices, and materials. The contractors will participate in developing and defining standards for the Shuttle Program. This includes recommending selection, specification, qualification, application, analysis, packaging, and installation procedures as standards to be used on the program.

Standardization of Program Element Standard Design Practices

Shuttle design standard practices will be established and used by the system contractors. These practices are as follows:

1. Standardized design approaches. This activity deals with determining commonality of design approach and considers such things

as threaded fluid fittings versus brazed or welded fittings; threaded fastener drive types, etc. Commonality here provides for uniform maintenance and logistics procedures.

2. Standardized manufacturing methods and fabrication processes. Within the limits of facilities, test equipment, and tooling, the contractors will utilize as many common methods as is practicable with the objective of reducing fabrication costs and maintaining an acceptable quality level.

3. Special handling and packaging requirements. The contractors will utilize common standards/procedures in the handling of explosives and hazardous material.

4. Contamination control. Common methods will be used for the definition and implementation of system cleanliness levels.

Standardization of Parts, Devices, and Materials

The contractors will utilize data on parts, devices, and materials which have been reviewed for specific shuttle design application and coordinated with NASA, its contractors, and subcontractors.

5.1.7 Human Factors

The contractors will provide a comprehensive human factors capability encompassing flight vehicles/SE/man-machine interfaces impinging on vehicle and ground system design and development. The following areas of activity and related tasks will be included:

1. Mission analysis: crew performance capabilities, hazard analysis

2. Operations analysis: crew/passenger loading and egress procedures (including abort and recovery)

3. System integration: man/machine interface, crew workload requirements, and crew station integration

4. Crew station displays and controls: flight crew operations requirements and preliminary procedures; panel arrangement criteria

5. Docking system: task requirements, visual/optical alignment aid requirements

5.1.8 Transportability

The contractors will incorporate design criteria for transportability into the orbiter/booster systems, and assure the early identification and resolution of transportability problems. In achieving adequate transportability, the contractors will comply with criteria in the following paragraph.

The flight vehicles, or as applicable, separable components/major subassemblies as well as ground equipment and support hardware, will be capable of being handled and transported by feasible transportation modes and carriers to applicable assembly, launch, recovery, and refurbishment sites or facilities without degradation of item reliability and utility. The item design will be compatible with the handling and transportation system to the extent that (1) no loads are induced into the item which will produce stresses above the mission allowable limits, (2) the item will be sufficiently protected from the natural environment, and (3) provisions have been made for necessary monitoring of in-transit loads.

Compatibility with Transportation System

In design for transportability, the vehicle system hardware characteristics will be analyzed and compared to the characteristics of selected or candidate transportation modes and carriers.

Induced Loads

Hardware items will be designed such that the methods used for handling and supporting them during transportation do not impose loads in the item in excess of the mission allowable stress levels. Consideration will be given to the fatigue life of the structure and to the loading spectrum from handling and transportation when assessing the induced load stresses against the allowable stress levels. Suitable analyses or tests will be conducted to account for handling and transportation induced loads and their effects.

Natural Environment

Hardware items will be protected against detrimental effects of the natural environment encountered during transportation and handling. The effects of the natural environment such as atmospheric pressures and precipitation, corrosion, and contamination will be accounted for by suitable analyses and/or tests.

Monitoring

During the periods when the item is being handled or transported, it may be necessary to monitor loads, temperature, pressure, etc., to ensure that the induced loads and the effects of the natural environment are within acceptable limits. Suitable analyses will be performed to establish need for such monitoring.

Transportability Report

The contractor will accomplish transportability planning to include the following:

1. Results of design analyses which identify and resolve transportability problems and demonstrate the contractor's compliance with transportability criteria and guidelines

2. Tabulation of all transportability problem items and applicable special transportation needs

5.2 ENGINEERING PROCESSES

The contractors will be required to provide the following basic engineering processes to support engineering and development of the elements of the space shuttle system.

1. Technical program planning (planning process)
2. Program work breakdown system (WBS) development (planning process)
3. Technical performance measurement (control process)
4. Technical problem solving (study process)
5. Technical study coordination (study process)
6. Specification preparation and maintenance (documentation process)
7. Drawing preparation and maintenance (documentation process)
8. Change planning and processing (documentation process)
9. Engineering release system (documentation process)
10. Interface control (control process)
11. Weight, volume, and mass properties control (control process)
12. Control of environmental criteria (control process)

13. Material properties analysis and material use control (control process)

14. Electrical load analyses (control process)

15. Signal list, measurement and controls (control process)

16. Safety assessments (control process)

17. Reliability assessments (control process)

5.2.1 Technical Program Planning

Planning of the system elements engineering and development efforts will be performed as an integral part of overall program planning. Planning requirements are established in the Program Management Plan.

5.2.2 Program Work Breakdown Structures (WBS)

The deliverable operational products will be integrated by the development of a program work breakdown structure (WBS) which will be the controlling baseline document for development of the system elements.

5.2.3 Technical Performance Measurement

A technical performance measurement (TPM) system will be implemented and maintained by the contractors. The TPM system will select significant performance requirements from the flight vehicle end-item specification to be identified for TPM tracking. The major parameters affecting the vehicle capability to meet the selected requirements will then be identified and statused. Statusing and monitoring of the lower level parameters will consist of the following:

1. Identifying the type of performance data available and method of data acquisition.

2. Establishing an acceptable performance level for each parameter; i.e., nominal and tolerances.

3. Establishing a schedule for management review of selected parameters throughout design and testing phases of the program.

4. Establishing a system to analyze the impact of off-nominal parameter performance and to recommend corrective action to Engineering and Program Management.

The TPM reporting system will become a part of the performance measurement system as required by the Program Management Plan.

5.2.4 Technical Problem Solving

Activities concerned with technical problem solving will be integrated into the overall corrective action program management system, defined in the Program Management Plan. Because many technical problems involve several of the system contractors concurrently, a responsive system will be established in order to integrate and expedite the achievement of a position from which technical direction can be initiated. The overall objective will be to recognize, define, and resolve technical problems and to implement resulting program/technical redirection as expeditiously as possible.

5.2.5 Technical Study Control

The contractors will establish control procedures for all major studies and devise methods of accepting, coordinating, and responding to technical study outputs from the system level. Contractors study activities that affect other system developers will be scheduled and controlled by the contractors, and the study status will be reported to NASA.

5.2.6 Specification Preparation and Maintenance

The contractors will prepare and maintain the contract, procurement, and process specifications required to satisfy program needs. The specifications will include the system end item performance, design, and test requirements. Specification requirements will be allocated from the Space Shuttle System Specification to the CEI specifications, subsystems, critical components, components, and processes.

Contract specifications will be prepared and maintained incrementally to support incremental end item reviews (PDR, CDR, SRR, and PCA). The orbiter/booster specifications will be updated by Specification Change Notice/Engineering Change Proposal (SCN/ECP) between Phase C go-ahead and PDR to reflect the system level and major system contractor requirements. Specifications identified below will be prepared initially to support PDR and updated by SCN/ECP to reflect the negotiated orbiter/booster configuration for CDR and PCA.

Contract Specification Preparation

Contract specifications covering the following will be prepared by the system contractors as applicable:

1. Orbiter prime item specification (CEI)

2. Booster prime item specification (CEI)

3. Main engine prime item specification (CEI)

4. Computer software development specification

5. Shuttle ground system specifications to include:

   a. Orbiter support equipment specification

   b. Booster support equipment specification

   c. Shuttle system support equipment specification

   d. Facilities design criteria specification

Contract Specification Maintenance

The contract specifications identified will be maintained in accordance with NASA Manual NHB8040.2 Exhibit VII, with the exception that page revisions shall be utilized in lieu of final SCN's, to preclude periodic specification revisions. Contract specification changes will be processed in accordance with NASA Manual NHB 8020.2, Exhibit IX.

Procurement Specification and Preparation Maintenance

Procurement specifications for subcontractor-furnished equipment will be prepared and maintained by the system contractors whenever:

1. Equipment must be developed and certified for orbiter/booster application

2. Supplier shelf items require control by acceptance testing.

Procurement specifications will be prepared and maintained in accordance withe the contractors in-house procedures.

Process Specification Preparation and Maintenance

Existing contractor process specifications will be utilized whenever such specifications satisfy orbiter/booster requirements. New process specifications will be prepared as required. Process specifications will be prepared and maintained in accordance with the contractors existing in-house procedures.

Government/Industry Specifications

Government and approved industrial specifications will be employed whenever such specifications satisfy orbiter/booster requirements. Government specifications (selected for use) will be those in effect (on or before date of issue) at the time of Phase C go-ahead. Changes to government specifications after the date of Phase C go-ahead will be negotiated with the contractors.

5.2.7 Drawing Preparation and Maintenance

The contractors will prepare and maintain drawings containing sufficient information to completely identify the configuration of equipment required to satisfy program needs. The drawings will delineate design solutions to requirements specified and controlled by applicable end item specifications. The contractor's drawing system will provide for the assignment and control of configuration identification numbers so that an audit of the as-built configuration can be accomplished. The contractors will prepare a drawing tree depicting the hierarchieal relationship of the drawings to the level required to satisfy end item requirements as defined in the applicable contracts. Drawing trees will be prepared in consideration of manufacturing and tooling requirements so that major parts and assemblies are properly sequenced for fabrication and installation.

Drawing Preparation

All drawings will be prepared to meet the requirements of MIL-STD-100 to the extent specified in MIL-D-1000 for Category E, Form 2 drawings, as modified by the contractor's approved drafting room manual.

Assignment of Drawing and Part Numbers

The contractor's drawing, and part numbering systems will meet the requirements of MIL-STD-100.

Application Data

Contractor drawing interrelationships will be maintained by entering drawing application data on the drawing or in the engineering release records.

Drawing Maintenance

The contractor's system for revising drawings will meet the requirements of MIL-STD-100. Drawings may be changed by an auxiliary document of the drawing rather than by drawing revision. Authorization for changing drawings will be in accordance with contractor change control systems.

5.2.8 Change Planning and Processing

Change proposals submitted from an integrated shuttle system level will be reviewed by the contractors to determine feasibility and impact upon specifications and other development activities.

Each proposed change will be evaluated for technical feasibility and determination of the nature of the change. Each change will be classified and assigned a processing category in accordance with classification criteria to be established by contract. Each validated change plan will include release dates for engineering documentation affected. The total change plan will include cost impact and be packaged under a single change identification number, together with proper authorization for implementation. Planned incremental implementation of change authorizations will be made when expedited handling is required. The release of changed documentation will be in accordance with and identified to a given authorized change package, and actual engineering release dates are to be reported and verified. Prior to the establishment of a contract baseline, change control is to be handled by informal methods. Formal change control procedures will be implemented only as appropriate for each phase of design and development, and after an approved requirement, design, or production baseline has been established.

5.2.9 Engineering Release

The engineering release system to be employed by the contractors will, as a minimum, identify the as-designed and as-modified end item configuration. Release requirements applicable to specifications, drawings, and change documentation are defined in the following subparagraphs.

Contract Specification Release (As-Specified Configuration)

Approved contract specifications will be identified by number and date of issue, and be released by the contractor's engineering release system. As specification change notices (SCN's) are approved, the SCN number will be released into the release system and be traceable to the parent end item specification. All approved waivers and variances will be released and identified to their applicable contract specification.

Procurement Specification Release

Procurement specifications will be identified by number and date of issue and released by the contractor's engineering release system. Approved changes to the procurement specification will be numbered and released and be traceable to the parent procurement specification. When the supplier part number becomes available, the number will be included in the engineering release file.

Drawing Release (As-Designed/As-Built/As-Modified Configuration)

The contractor's engineering release system will reflect released drawing data including part number identification, revision letters, change points, engineering order numbers, quantity per end item, next assembly, etc., and provide a capability for information retrieval that will, on demand, provide the basic information elements for configuration management.

The engineering release system will also be capable of furnishing the engineering design data necessary for correlation with manufacturing test and logistics records to provide a record of the as-built and as-modified configurations.

The release system will reflect change status, engineering change proposals (ECP), and modification kit installations to establish the as-modified configuration.

5.2.10 Interface Control

Interface control for the system elements will be conducted in conformance with the overall requirements established in Paragraph 4.4 of this volume. Primary emphasis will be placed on being fully responsive to requirements/procedures of the interface control working group (ICWG) which is responsible for controlling all technical interfaces with external systems and among the major Space Shuttle Program functions (i. e. , orbiter development, booster development, etc.). The NASA center and the orbiter/booster contractors as required will sit as members on the ICWG. The assigned technical management members will have sufficient authority to ensure that the necessary responsiveness is provided by his center/company. Responsibilities of the ICWG are discussed in detail in the program management plan.

System element external interfaces (functional, physical, and procedural) will be documented in interface control documents (ICD's) which in turn will be incorporated by reference in the appropriate specifications. Since extensive detail design efforts cannot be effectively initiated until the controlling external ICD is formally released, comprehensive early planning is a necessity. All requirements for external ICD preparation will be formally transmitted to the ICWG chairman for inclusion in the interface control plan. Since this plan will be updated periodically and will implement any major program/technical redirection, it will be utilized to control all efforts supporting external ICD development. The contractors will expeditiously report all actual and anticipated plan deviations to the ICWG chairman along with the recommended progress recovery solution. In addition, the status of all external ICD's will be formally transmitted to the ICWG chairman once a month.

Interfaces internal to the system elements will be controlled by the contractors normal management practices.

5.2.11 Weight, Volume, and Mass Properties Control

The contractors will establish a mass properties control program to satisfy the intended requirements of SP6004 and MIL-M-38310A (USAF). The concept to be used for reporting purposes will be approved by NASA. The mass properties base will be those mass properties defined by the approved orbiter and booster specifications. The format to be used for reporting purposes will be similar to that used for aircraft applications (e. g. , AN 9102 and AN 1903 forms, and supplemental design data sheets). Initial mass properties and volumetric data will be derived analytically from structural layouts and subsystem schematics.

Similar data will be provided by system element subcontractors and suppliers. These data will be combined and documented in periodic status reports. At completion of orbiter and booster 90-percent original drawing release, a detail mass properties report will be submitted to NASA. The contractors will derive and maintain mass properties data for all mission phases. Sufficient design data will be provided for all major subsystems to substantiate the reported mass properties.

5.2.12 Control of Environmental Criteria

Control of environmental criteria will be established at the integrated shuttle system level within the technical cognizance of NASA. The external and natural environments will be established and imposed upon the contractors for uniform application of environmental design criteria. The ground test levels to show compliance with these environments will also be defined and imposed on the contractors for use in establishing a common base for test criteria.

For design purposes, the natural environments as defined in NASA documents TMX-53952 and TMX-53872 will be utilized. The contractors will define induced environments for the assigned system elements. Induced environments will be confirmed by vehicle testing.

The contractors will establish and control environmental criteria for uniform application to each system element and its interfacing elements. Environmental criteria documents will be specified in the appropriate orbiter and booster specifications.

5.2.13 Material Properties Analysis and Material Use Control

The contractors will provide the appropriate procedures for selection and control of materials for the system elements. Materials will be characterized in sufficient detail to permit reliable and high-confidence prediction of material properties. Material characterization will include determination of (1) general physical properties including thermal characteristics; (2) design allowable mechanical properties; and (3) material failure mechanisms.

Physical and mechanical properties of materials including structural joints will be obtained from sources such as MIL-HDBK-5, MIL-HDBK-17, MIL-HDBK-23, and the contractor's standard materials properties manuals. Where values for physical and mechanical properties of new materials and joints or existing materials and joints in new environments are not available, they shall be determined. Analytical and test programs, dictated by good engineering practice, will be employed.

Failure mechanisms related to life limiting phenomena will be established and controlled.

Compartments for personnel will not utilize materials which present a hazard of a noxious toxic or flammable nature under the expected operating environment.

6.0 POTENTIAL TECHNICAL PROBLEMS

This section identifies those areas representing a potential development risk which may impact the schedule or seriously impair the performance of the space shuttle system. Areas of concern are summarized in this volume by mission phase (Section 6.3) with a brief statement of the nature of the problem. The details of the problem and the required approach are discussed in Volumes II and III of this plan, as appropriate, associated with the system element that will be most seriously impacted by the problem.

This section also addresses the basic requirements to be utilized for technical risk assessment and similar requirements for obtaining solutions to major technical problems.

6.1 TECHNICAL RISK ASSESSMENT

The probability of not achieving program technical goals (risk assessment) will be determined at both the system and subsystem levels where potential program impact is indicated. Program level criteria will be used to select system problems for technical risk assessment. The objectives of technical risk assessment are:

1. Perform and update evaluations of system technical risk as a means of identifying and assessing the impact of critical technical problems.

2. Assess and forecast actual engineering costs and schedules with reference to the probability of meeting planned cost, schedule, and performance values.

3. Develop recommendations for maximizing technical program accomplishments commensurate with acceptable risk.

4. Support program and prime item reviews conducted to determine if replanning of the technical program is required based on program/problem status.

5. Identify and recommend potential areas for redirection of the program technical effort to reduce cost and time and balance the degree of risk assumed throughout the system.

6. Utilize results of technical risk assessment in technical problem solving.

6.2 TECHNICAL PROBLEM SOLVING

Technical problems involving the program are divided into two categories: (1) those including system elements of other major development functions, and (2) those entirely with the scope of a single system element. Problem solution minimum requirements for both categories are:

1. Identify and define problems affecting the program and all prime items.
2. Assign and schedule responsibility for technical problem solving.
3. Ensure that system/program factors are properly considered including impact on system cost, schedule, and performance.
4. Coordinate and expedite technical problem solutions and evaluate.
5. Determine alternate solutions, and define recommended course of action with supporting rationale for selection.
6. Verify effectiveness of solutions implemented.
7. Document technical problem definition and resolution and provide permanent traceability to source of requirements affected (i.e., specifications, ICD's, plans, etc.).

The overall objective is to recognize, define, and resolve technical problems and to implement resulting program/technical redirection as expeditiously as possible.

6.3 SYSTEMS OPERATIONAL PERFORMANCE POTENTIAL PROBLEM SUMMARY

In order to identify problems and potential problem areas, it is necessary to examine the total system in terms of its ability to satisfy mission (performance) requirements. This, then, requires that the ability of system elements, element subsystems, and subsystem components be examined in terms of required functional capability and performance level. The following paragraphs identify and discuss possible problems and/or problem areas based on the current system and requirements definition. In general the discussion is addressed to operational and functional aspects of the system elements. Technology problems, payload performance, and subsystem design/development are not specifically treated. Since the development phase includes manned orbital flights, the discussion is arranged in terms of mission chronology.

6.3.1 Mating and Checkout

The development of procedures and software to effectively accomplish element premated checkout, mating, and mated checkout must consider such factors as checkout accomplished during refurbishment, time since refurbishment, and payload installation and checkout requirements. Although they do not present unique problems, careful attention to these operations can appreciably reduce cost and time. Attention will be given to the early elimination of those activities which can be termed operational confidence checks, particularly as they relate to non-safety critical functions.

6.3.2 Prelaunch

This includes transportation from the assembly/checkout area to the launch pad and prelaunch checkout. The longitudinally unsymmetrical vehicle arrangement coupled with relatively large lifting surfaces can produce an undesirable surface wind sensitivity unless careful attention is given to these aspects during facility and SE definition and design.

6.3.3 Launch and Mated Ascent

Vehicle tie-down release and liftoff is obviously the first critical phase of the mated ascent operation. This, plus the parallel arrangement and lifting configurations, can result in unique drift and tilt problems. These, in turn, can impact both flight element and facility design. A significant factor in preventing a problem in this area is timely incorporation of adequate model test data and full-scale data from other programs, if applicable. These data are required not only for launch but also for definition of the prelaunch design implications of surface winds.

The region of high dynamic pressure coupled with large pitch and/or yaw angles tends to impose design requirements on the control system and to a large degree result in vehicle design loads as well. Even with the most detailed analytical and model test approach, the mated aerodynamics of a full-scale vehicle will be somewhat doubtful. Therefore, it will probably be desirable, through utilization of the flight control system and/or engine throttling, to restrict max Q alpha or Q beta during early vertical flights. Data also indicates that the maximum orbiter/booster attach loads occur during the 3-g acceleration period. It may therefore be desirable to approach this condition with caution.

Although detailed analysis will be performed and redundant design features incorporated, the possibility of system failure throughout flight must be considered. Providing intact abort for all situations is desirable from both a safety and economic standpoint. However, the feasibility of providing such coverage, when balancing possible need against definable design, operational, and cost impacts has yet to be assessed. Even when this aspect of the analysis has been completed, the possibility of total thrust loss or a similar occurrence early in flight will pose a range safety problem when considering all-azimuth (toward/over populated areas) launch. Therefore, the problems related to achieving early impact-point control of the mated or separate elements should be addressed to achieve maximum capability with minimum system impact.

6.3.4 Separation

Stage separation is one of the most critical operations in that, unless it can be safely accomplished, neither mission completion nor mission abort can be achieved. Hence, even if problems were not obvious, those subsystems of the orbiter and booster required for separation would need close monitoring to preclude solution-induced problems. The ability to perform stage separation at essentially any time during mated flight is a desired, if not a required, capability. Studies conducted to date of separation system concepts have broad implications on overall system design for an any-time separation capability. However, the analysis in some areas has not proceeded to the point where the capability or necessity for immediate separation can be assessed. It appears desirable to have a separation system that, to as large a degree as possible, is independent of other systems, e.g., failure which would not preclude safe recovery of one or both flight elements if separation were possible should not prevent separation.

6.3.5 Orbiter Ascent

The major potential problems during orbiter ascent are related to provisions for intact abort resulting from a failure. It is obvious that failures or failure levels which preclude mission completion but do not represent a safety hazard are important. However, of more significance are those failures which not only preclude mission completion but create a hazardous condition. The primary failure considered is loss of thrust from one main engine. Loss of TVC of one engine could require that the engine be shut down in order to maintain roll control; hence, the effect would be the same as loss of engine thrust.

The three possible methods envisioned for accomplishing intact abort under these conditions are (1) once-around abort (requires reaching burnout conditions corresponding to an orbit which results in first-pass entry with recovery in the CONUS), (2) abort to orbit (requires injection into low earth orbit with subsequent de-orbit and recovery), (3) downrange abort (requires the capability to utilize propellant energy and aerodynamics to reach a recovery site without entering orbit).

Study to date has shown that the first two approaches compromise the vehicle design in that the orbiter size and/or payload capability is determined by the orbit maneuvering system energy available (since this is required to compensate for the increased energy requirements resulting from the reduced vehicle thrust-to-weight ratio). The third approach, while not constraining orbiter size, does result in launch azimuth constraints and imposes requirements on engine-out control capability. The most reasonable approach at this time appears to be a combination of the above, i.e., the use of downrange abort for failures occurring early in the orbiter ascent and utilization of once-around and abort-to-orbit options as they become available during ascent due to reduced abort energy requirements.

6.3.6 On Orbit

This includes all on-orbit operations including propulsive maneuvers, docking, payload handling and de-orbit. The orbit maneuvers should present no major problems. However, the implications of an OMS engine failure need to be considered in terms of software requirements and perhaps GN&C functions, particularly with regard to de-orbit. Failure of an engine to light would result in a downrange shift in the burn completion point of approximately 150 miles.

The current scheme utilizes a remote manipulator to assist in docking and perform payload transfer or deployment. A potential development problem envisioned for this system is providing adequate testing at one g of a minimum-weight system designed for zero-g operation. A primary consideration relative to the payload bay and payload deployment is that subsystem design should preclude any failure modes preventing proper closing of the payload doors.

Any requirements arising from unique payload handling and deployment characteristics must be evaluated as they become known.

6.3.7 Entry

The primary entry problem is assuring control adequacy without excessive overdesign of vehicles which do not have outstanding flight characteristics. As in the case of mated flight, the uncertainties in full-scale aerodynamics must be carefully considered. In addition, the ramifications of entry trajectory dispersion, mass property variations, and extent of pilot control capability will be stressed early in the program to preclude subsequent problems or capability limitations.

6.3.8 Landing

There is an inherent problem source in the design/development of a vehicle having automatic or pilot-controlled landing capability. This stems from the fact that in general an aircraft designed for and operated within the limits of pilot capability can be automatically landed; however, the reverse is not true. Thus, in the course of system development, operational and design requirements must consider pilot control as the primary mode. The baseline system is manual landing with the capability of automatic landing and the provision of pilot manual landing takeover in the event of a malfunction during the automatic landing phase.

Another potential problem arises from the requirement that the orbiter air-breathing engines can be removed to ultimately satisfy mission performance requirements. It is possible that vehicle characteristics, such as G&N accuracies and operational requirements, could preclude total removal of this subsystem. Therefore, a detailed evaluation of the relation of these factors to the degree of powered flight capability required (i.e., go-around, cruise, range extension and/or glide slope reduction or none) must be made to assure confidence in the projected capability.

The once-around abort capability of the orbiter to land at the launch site can introduce an operational problem since minor variations in the orbiter entry and/or booster flyback could result in both vehicles being in the landing pattern at the same time. Thus flight capability or facility provisions to accommodate this situation may be required.

6.3.9 Postlanding

No specific problems are envisioned in this area; however, the requirement of safing, postlanding checkout, and transportation to the refurbishment facilities for both primary and emergency landing sites must be considered.

6.3.10 Horizontal Flight Test

The horizontal takeoff flight test program has essentially the same goals and employs the same approach as that of conventional aircraft. Therefore, the problems will relate to structuring the flight test program to yield the maximum useful data considering that the test regime covers only a small portion of the operational envelop encountered in the mated test program.

7.0 SPACE SHUTTLE PROGRAM MASTER SCHEDULE

The purpose of the Program Master Schedule is to identify the principal phases and hardware elements of the program and to establish milestone dates for their achievement in a manner that permits more detailed scheduling and progress statusing.

Figure 7-1 shows the integrated activities and major milestones that indicate shuttle system progress through design, development, manufacturing, and ground and flight testing to the point of demonstrating operational capability. This schedule will be used as the baseline for planning the activities for development of system elements. All supporting schedules will be keyed to the Program Master Schedule.

The program schedules will be developed using a program work breakdown structure (WBS). The program WBS and its dictionary presented in SD 71-124-3 define the shuttle system elements and supporting subsystems and operations essential to the development of the space shuttle system.

A logical order of the development phases of the program and related support equipment establishes the sequence, constraints, and interdependency of activities and events that are necessary to the achievement of an operational system. The development logic supporting the Master Program Schedule is presented in Section 4.0 of this volume.

7.1 MASTER PROGRAM SCHEDULE (MPS-05) GROUND RULES

The significant program ground rules that influenced the development of the Space Shuttle Master Program Schedule (MPS-05), Figure 7-1, are identified as follows:

1. Assumed Phase C/D go-ahead is 1 March 1972.

2. First horizontal flight is scheduled for June 1976.

3. First manned orbital flight is scheduled for April 1978.

4. The shuttle will be operational by mid-1979.

5. Immediately following Phase C/D go-ahead, a 3-month period will be utilized to resize the orbiter and booster vehicles, to refine Shuttle system requirements, and to define the management and technical approach to the implementation of the Phase C/D Program.

6. Preliminary Design Reviews (PDR's) are scheduled according to a specific phasing plan that allows constraining items to proceed into detail design in a timely manner to support fabrication of the first flight vehicle.

7. 95-percent design release will occur approximately 9 months prior to the completion of the first orbiter and booster flight vehicles.

8. Drawing releases will be initiated incrementally upon completion of PDR's on the appropriate subsystems.

9. The manufacturing rate between major test articles and flight vehicles is based on minimizing duplication of major structural assembly tooling.

10. Orbiter and booster components, subsystems, and support systems will be certified on an incremental basis in order to support the horizontal and vertical flight test programs.

7.2 PROGRAM SCHEDULE ANALYSIS

The following paragraphs present the rationale for the schedule.

1. The engineering design process and design reviews are time-phases to permit the detail design and specification releases to support the manufacturing modular buildup concept; that is, large sections of the fuselage and subsystems are assembled and checked out individually and subsequently mated to produce the completed vehicle and culminate with an integrated systems checkout prior to preflight activities.

2. The early time-phasing of the first flight vehicle prior to the structural test article in the program was necessary to meet the first horizontal flight date of June 1976. However, this sequence still allowed 8 months of static testing up to limit loads prior to the first horizontal flight. A more desirable sequence would be to reverse the order of these two vehicles and allow more structural testing to be completed earlier in the program, which would result in minimizing structural design changes prior to building the first flight vehicle. An additional advantage to manufacturing a ground test article on newly built tooling is to

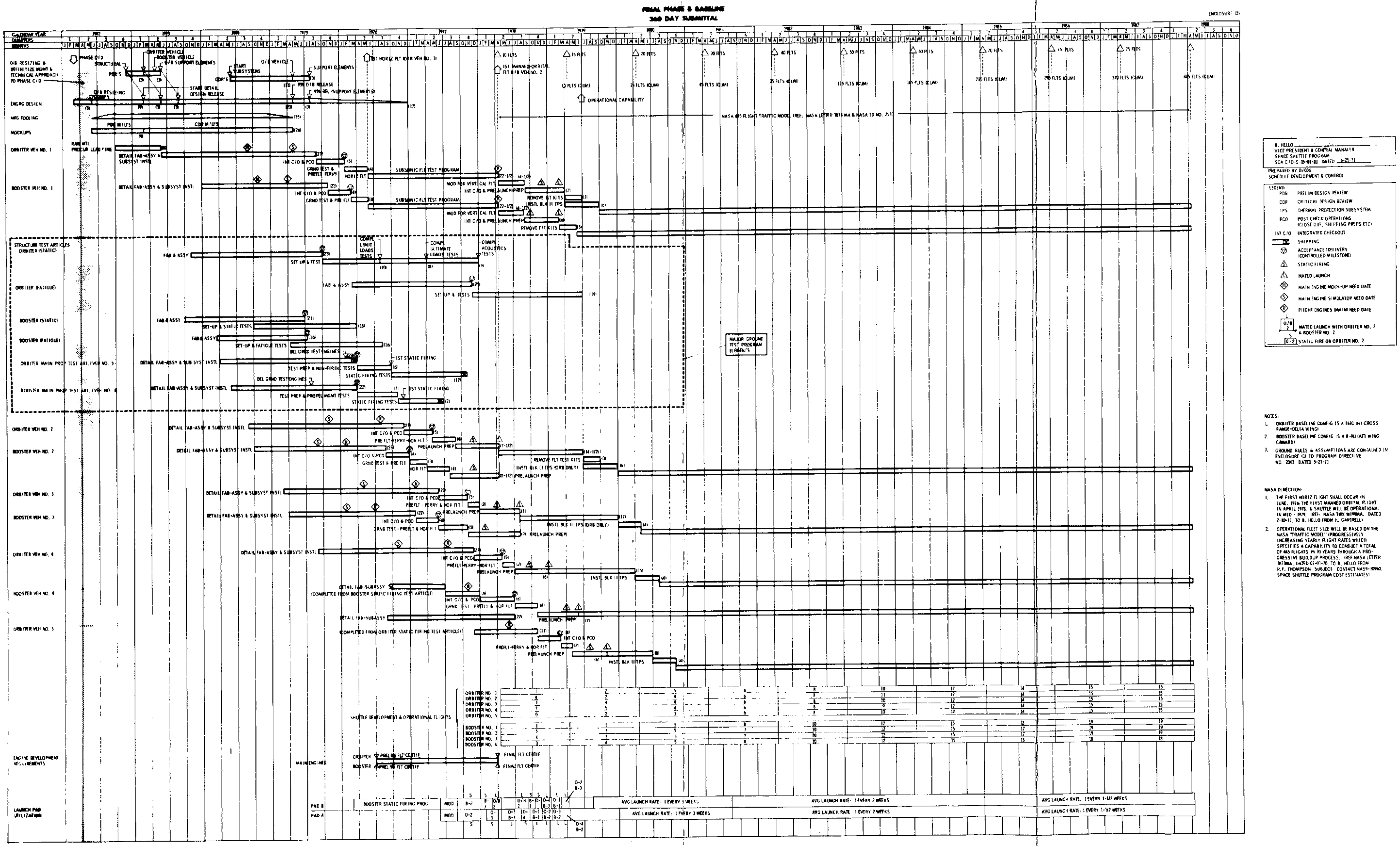

Figure 7-1. Space Shuttle Phase C/D Master Program Schedule

7-3, 7-4
A

7-3, 7-4
B

provide improved confidence in the quality of the first flight vehicle. The present sequence does allow 22-1/2 months of subsonic flight testing prior to the first manned orbital flight; however, analyses and comparative data from past airplane test programs indicate that a 12-to-18-month subsonic test program would be sufficient.

3. The main propulsion test article, utilized to develop the main engine cluster and its propellant feed and pressurization system, is a prerequisite to the first manned orbital flight scheduled for 15 April 1978. Current analyses show a requirement for 12 months of static firing tests (12 to 14 full-duration firings) to adequately qualify the propulsion subsystems and acquire data to assess the susceptibility of the orbiter configuration to pogo effects.

4. Development and qualification testing of components and subsystems will be accomplished on a selective basis and scheduled in such a manner as to allow portions of subsystems to be qualified incrementally to support the first horizontal flight.

5. The flight test program is phased to allow adequate time to perform low-amplitude dynamic tests prior to the first flight on the first flight vehicle.

APPENDIX

COMMONALITY CANDIDATE LIST

SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Integrated Avionics

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Integrated avionics subsystem (includes communications, GN&C, D&C, DCM, instru and PD&C)		x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Subsystem lends itself to common development. Subdivide into manageable subsystems for development (i.e., GN&C, DCM, D&C, communications, instrumentation and PD&C).
Communications (includes atmospheric navigation aids)		x							Develop as orbiter system. Delete functions not required for booster operation.
	Interrogater antenna	x							
	Precision ranging interrogaters (PRS)	x							
	Signal processor					x			
	Flight log recorder					x			
	Audio center					x			
	UHF transceiver (ATC)					x			
	VHF recovery beacon					x			
	ATC transponder					x			
	Radar altimeter	x							
	UHF antenna (ATC voice)		x						
	L-band antenna (ATC transponder)/ selector		x						
	S-band antenna/selector					x			
	S-band power (amplifier) eqpt			x					
	USBE			x					
	UDL			x					
	VHF antenna			x					
	C-band ant. (radar altimeter)		x						Orbiter only -- all phases voice, data and commands.

A Develop as a common item
B Potential common item
C Vehicle-unique
D Government-furnished equipment
E Common (Off the Shelf), no development

SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Integrated Avionics

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
Communications (Cont'd)	VHF/FM transceiver			x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Orbiter only -- on-orbit commands, voice, data and navigation with TDRS.
	S-band transmitter			x					Booster only -- (DFI).
	Booster/orbiter data link	x							
Displays and Controls		x							
	Translation controller assy			x					Orbiter only.
	Rotation hand controller assy					x			
	Rudder, nose-wheel steering pedal assy			x					Structural configuration unique.
	CRT displays/electronics	x							
	Alphanumeric displays	x							
	Entry control keyboard	x							
	Caution-warning display modules	x							
	Flt cont mode select panel			x					Added modes in orbiter, not in booster.
	Navigation mode select panel			x					
	Throttle control assy			x					Engine configuration unique.
	Time readout displays					x			
Data and control management system (does not include data bus)		x							
	Main storage unit	x							
	Central processing unit	x							
	I/O bus control unit	x							
	Mass memory unit	x							

A Develop as a common item
B Potential common item
C Vehicle-unique
D Government-furnished equipment
E Common (Off the Shelf), no development

SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Integrated Avionics

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
Software	Vehicle; common data base	x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		
	Support program	x							
	Flight program			x					
	Flight program verification			x					
	Support equipment program			x					
	Support equipment verification			x					
	Guidance package			x					

A Develop as a common item
B Potential common item
C Vehicle-unique
D Government-furnished equipment
E Common (Off the Shelf), no development

SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Integrated Avionics

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Data Bus		x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Hardware identical, data bus, act and line coupling units tailored to unique requirements.
	ACT unit	x							
	Line coupling units	x							
	ACT/select buffer	x							
Guidance, navigation & flight controls (excl RF nav aids)		x							Orbiter requirements determine design performance, orbit insertion, on-orbit maneuvers, rendezvous/docking, entry, atmospheric operations.
	IMU (platform) & power supply	x							
	Rate gyro package	x							
	Star tracker equipment			x					Orbiter only.
	Air data package					x			
	ABES throttle control driver			x					Vehicle unique.
	TVC gimbal drivers			x					Orbiter only.
	Aero surface driver(O)/TVC gimbal driver (B)	x							
	Aero surface driver			x					Booster only.
	Attitude/trans driver (4 jet)			x					Orbiter only.
	Attitude/trans driver (2 jet)			x					Orbiter only.
	Backup sighting unit			x					Orbiter only.
Power distribution & control				x					Power distribution system vehicle unique. Develop common components to extent possible.
	Inverter			x					Orbiter only.
	Power controllers	x							
	Wire/connectors					x			
	Transformers/rectifiers	x							
	Generator control unit	x							
	Generator current transformer	x							
	Battery charger			x					Orbiter only.
	Sequencer			x					Unique pyro circuits.

A Develop as a common item
B Potential common item
C Vehicle-unique
D Government-furnished equipment
E Common (Off the Shelf), no development

SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Integrated Avionics

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Instrumentation (includes DFI)			x				TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Substantial commonality. System design will be unique, but uses large proportion common components.
	Signal-conditioning packages		x						
	Sensor-conditioning packages		x						
	Recorders	x							
	Master timing unit	x							

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Vehicle Support

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Vehicle support subsystem (includes crew provisions, EC/LSS and hydraulics)				x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Total subsystem generally does not lend itself to common development. Substantial cost savings possible through common development of selected components.
EC/LSS subsystem									
	Cabin press. relief valves		x						
	O_2 bottles (2 hrs emergency supply)	x							
	Cabin temperature sensor	x							
	Temperature transducer	x							
	Temperature signal amplifier	x							
	Face mask	x							
	Regulators	x							
	Miscellaneous instrumentation		x						
Electrical power generation subsystem				x					Installation and power demands are vehicle-unique. However, many components of subsystem and similar orbiter/booster subsystems can be developed as common items.

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Vehicle Support

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
Fuel cell power plant				x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Orbiter only. Other application such as space station not sufficiently defined to establish commonality.
Battery		x							
H_2 super-critical dewar				x					No requirement on booster for supercritical H_2 or O_2 storage -- orbiter only.
O_2 super-critical dewar				x					

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Vehicle Support

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
APU subsystem				x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Unique power levels and installations.
	APU module	x							
	AC generator	x							
	Isolation valves	x							
	Plumbing installation			x					Vehicle unique. Commonality in materials, fittings & bracketry.
Hydraulic subsystem (includes TVC, aero flight control, landing gear and brake actuator functions)				x					Installation and power requirements are vehicle unique. However, approximately 80 percent of major components can be developed as common items.
	Pumps		x						
	Motor pumps			x					Orbiter only.
	Reservoirs		x						
	N_2 storage bottles	x							
	Filters		x						
	Valves	x							
	Pressure transducers	x							
	Temperature transducers	x							
Hydraulic main engine gimbals	Servo actuators			x					Vehicle-unique.
	Valves		x						

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Vehicle Support

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Hydraulic aerodynamic flight control	Servo actuators			x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		
	Control servo assembly			x					
	Transducers	x							
Hydraulic nose and main landing gear and brake	Actuators			x					
	Valves		x						
	Accumulators		x						
Hydraulic engine deployment	Rotary actuator, motor, gearbox		x						
	Door actuator			x					
	Valves		x						

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Vehicle Support

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
Personnel provisions	Not applicable			x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Mixture GFE/CFE development.
	Ejection seat and restraints*	x							Carriage/attach assys unique.
	Crew seat and restraints*		x						
	Coveralls	x			x				
	Elec/comm umbilical	x							
	Life vest	x			x				
	Sun glasses	x			x				
	Pen lights	x			x				
	Chronograph and band	x			x				
	Motion sickness bag	x			x				
	Crew survival kit		x		x				
	Crew life raft	x			x				
	Crew escape rope		x						
	Bioinstrumentation	x			x				
	Constant wear garment (underwear)		x		x				
	Headset	x			x				
	Pencil	x			x				
	Medical kit(s)		x		x				
	Binoculars		x		x				
	Portable floodlights		x		x				
	Personal preference kit			x	x				
	Camera, lenses, film, etc. (some)		x		x				
	Press garments & accessories (flight test only)	x			x				
	O_2 masks	x							
	Evacuation reels	x							
	Fire extinguishers		x						
	* Some noncommon components may be required in assembly								

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Propulsion

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Propulsion (includes main rocket engines, ABES, ACPS and OMS)				x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Wide range of technology involved over the spectrum of engines required with differing requirements between the two vehicles make a totally common development approach unattractive. However, generally compatible with common development of subsystem components -- components approximately 80 percent common.
Main rocket engine subsystem				x					
Main rocket engine subsystem		x			x				Power heads can be developed as common item; exit nozzle subassembly is most significant noncommon item.
Propellant tanks and feed line assembly	Not applicable			x					Tank volume requirements, line lengths and shape substantially different. Many high-cost valves and components can be developed as common items because of selection of identical line sizes on both vehicles.
	Disconnects		x						
	Propellant lines, gimbals		x						
	Propellant tanks			x					
	LO_2 & LH_2 fill & drain valves	x							
	LO_2 & LH_2 vent valves	x							
	LO_2 & LH_2 prevalves	x							
	He valves								
	Regulator		x						
	Check	x							
	Solenoid	x							

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Propulsion

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
	Instrumentation	x					TO BE DETERMINED DURING PHASE C/D NEGOTIATION		
	LO_2 and LH_2 point sensors	x							
	POGO suppression		x						
	Engine avionics interface		x						
	Engine interface	x							
	Engine pressure isolation check valve	x							
ACPS Subsystem									Propellant quantities and storage requirements differ widely between the vehicles. However, most engine assemblies and components can have common development.
	Thrust chamber assembly	x							Can be made identical.
	Turbo pump assembly		x						Different NSPH, capacity, pressure levels and control functions.
	GO_2 heat exchanger		x						Different operating pressure and capacity.
	GH_2 heat exchanger		x						Different capacity booster 1.5 times orbiter capacity.
	GO_2 accumulator		x						Different storage pressure.
	GH_2 accumulator	x							Common requirements and design.
	Distribution components								
	Valves	x							High-cost propellant feedline and pressurizing valves will have common development.
	H_2 & O_2 relief								
	H_2 & O_2 fill & drain								
	H_2 & O_2 pressure regulator								
	H_2 & O_2 check								
	H_2 & O_2 isolation								

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: PROPULSION

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
	Instrumentation	x					TO BE DETERMINED DURING PHASE C/D NEGOTIATION		
	Propulsive/nonpropulsive vent			x					Not required on booster.
OMS Subsystem				x					Unique to orbiter.

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Propulsion

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
ABES subsystem				x			TO BE COMPLETED DURING PHASE C/D NEGOTIATION		Differing propellant quantities and installation requirements. However, most major assemblies and components can be developed as common items.
	Air-breathing engine assy	x							Booster vehicle will have most stringent requirements for thrust uprating and source of greatest change activity.
	Propellant tank & feed assy			x					Grossly different tank shapes and volumes for the two vehicles.
	Boost pumps		x						Shelf-type equipment -- booster requires higher flow, larger pumps or more pumps if commonality with orbiter is to be achieved.
	Valves		x						High-cost valves will have common development. Shelf-type hardware to be used where applicable.
	Fill and drain								
	Vent relief								
	Isolation								
	Level control								
	Instrumentation	x							A majority of components common. Some unique requirements because of system design difference.
	Point sensors	x							
	Fire extinguishing/detection system		x						Shelf-type equipment.
	Gaging system		x						
	Engine thrust control		x						
	Starter (engine)		x						

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Support Equipment

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Support equipment		x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		
	Anthropomorphic dummy	x							
	Electric drive	x							
	Gearbox	x							
	Horn and antenna set	x							
	A-C power supply	x							
	Truck-fire	x							
	Truck-safety	x							
	Maintenance transportation - pickup truck	x							
	Kit-rescue equipment	x							
	Crane-mobile	x							
	Cover-ABES intake	x							
	Cover ABES exit	x							
	Pin-landing gear safety	x							
	Weighing system	x							
	Air transport-GSE & LRU	x							
	M & R bus switching unit	x							
	Support console, ground display and control	x							
	Launch control bus switching unit	x							
	Ground bus interface select buffer	x							
	Ground bus control unit	x							
	Ground bus interface	x							
	Vehicle data bus simulator	x							
	Support equipment simulator	x							
	Communications test console	x							
	Rate table	x							
	Nav displace table & console	x							

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Support Equipment

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
	Protractor-control surface	x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		
	Tractor-aircraft towing	x							
	Launcher-mobile	x							
	Vehicle-crew egress	x							
	Escape system-flight crew, launch pad	x							
	Jack-alligator	x							
	Jack-tripod	x							
	Rack-jet engine cowling	x							
	Wheel chocks-booster-set	x							
	Dolly-rocket engine	x							
	Dolly - booster/orbiter jet engine	x							
	Dolly - main landing wheels	x							
	Dolly - nose landing gear	x							
	Crawler - transporter	x							
	Truck-fork lift	x							
	Ground AC power supply	x							
	Nitrogen distribution unit	x							
	Purge control unit	x							
	Water servicing unit	x							
	Pneumatic launcher valve unit	x							
	Nitrogen launcher purge unit	x							
	Hydraulic ground cart	x							
	Pneumatic launcher distribution unit	x							
	Hydraulic load bank ± reservoir	x							
	Nitrogen valve panel	x							
	Hydraulic supply unit	x							
	GO_2 recharger	x							

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Support Equipment

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
	Pneumatic test stand	x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		
	Hydraulic test stand	x							
	JP test stand	x							
	Lube oil servicing unit	x							
	JP servicing unit	x							
	Hydraulic power unit	x							
	Nitrogen panel	x							
	Pressure reduction panel	x							
	Regulation panel	x							
	Nitrogen heat exchanger	x							
	Helium heat exchanger	x							
	LN_2 valve panel	x							
	Nitrogen valve panel	x							
	Helium valve panel	x							
	GN_2 valve panel	x							
	Water test stand	x							
	ABES servicing unit	x							
	Pneumatic starter cart	x							
	Liquid hydrogen catch tank	x							
	Liquid oxygen catch tank	x							
	JP catch tank	x							
	JP tank truck	x							
	Gaseous nitrogen trailer	x							
	Nitrogen distribution unit	x							
	Purge control unit	x							
	Sample kit-oxygen	x							
	Sample kit-gases	x							
	Sample kit-fluids	x							
	Lubrication servicing unit	x							
	Oil analyzer-ABES	x							
	Port module leak test unit	x							
	Hydrogen leak detector	x							

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Support Equipment

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
	Communications/navigation system tester	x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		
	Electrical test load bank	x							
	Gen purpose digital computer (GDC 6600 class)	x							
	Manned spaceflight network	x							
	UHF communications set	x							
	Pneumatic distribution unit	x							
	Pneumatic test set	x							
	VHF/UHF test bench	x							
	L-band, C-band test bench	x							
	S-band test bench	x							
	Maintenance test adapter kit	x							
	IMU test station	x							
	Core memory extender	x							
	Analog test station	x							
	Digital test station	x							
	Central data bank model	x							
	DCM test station	x							
	Electrical load bank	x							
	Ground data bus system	x							
	Automatic circuit analyzer	x							
	Mobile control & display unit	x							
	He mass spectrometer leak detector	x							
	KSC flt tests DPI data sta	x							
	Pyro simulator unit	x							
	Shorting plug set-ordinance	x							
	Operational site cable set	x							
	Electrical test station	x							
	Final assy test adapter kit	x							
	Equipment-inspection	x							

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Support Equipment

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
	Gas sampling unit	x					TO BE COMPLETED DURING PHASE C/D NEGOTIATION		
	Battery charging unit	x							
	High press GO_2 launcher valve unit	x							
	High press GH_2 launcher valve unit	x							
	Pheumatic control unit	x							
	Swingarm control unit	x							
	Pneumatic unit	x							
	Alignment set--engines	x							
	Protective pressurization unit	x							
	Cart--lubrication servicing	x							
	Access stands airs surfaces	x							
	Cleaner--vacuum	x							
	Arm--separation link access	x							
	Full mission simulator	x							
	Procedures trainer	x							
	Ingress-egress & familiarization trainer	x							
	G trainer	x							

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Facilities

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
Facilities test	Structural test, component and section level		x						
	Antenna pattern testing		x						
	EC/LS testing		x						
	Crew escape module rocket sled test		x						
	MPS propellant mgt test and cluster firing		x		x				
	MPS component development		x						
	Avionics sys component dev		x						
	Hydraulic sys component dev		x						
	Auxiliary propulsion system component dev		x						
	Power generation system component dev		x						
	ABES testing		x						
Development test	Main propulsion system test		x						
	Orbit maneuver system		x						
	Attitude control propulsion system test		x						
	Air-breathing engine sys test		x						
	Power generation subsys test		x						
	Avionics subsystem		x						
	Integration test		x						
	Structural test		x						
	Ground vibration test		x						
	Thermal vacuum test		x						
	Hydraulic system test		x						
	Flight technology		x						
	Antenna pattern testing		x						

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Facilities

Subsystem	Major Components	Commonality Category					Development Responsibility (Contractor/Center)		Discussion
		A	B	C	D	E	Orbiter/MSC	Booster/MSFC	
	Crew escape system test		x						
	Life systems support test		x						
	Human factors testing		x						

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E Common (Off the Shelf), no development

SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Training

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Training equipment	Proficiency training aircraft				x				
	Full mission simulator	x							The simulator which handles both the booster and orbiter is procured as one item under one performance specification. There are elements within the device which are unique, however, such as the cockpits.
	Procedures trainer	x							
	Ingress-egress trainer	x							The trainer, for purposes of economy, is constructed to handle both booster and orbiter activities. Many elements of the training, however, are unique to the booster or orbiter.
	"G" trainers	x							
	Mfg. spec. processes trainers		x						
	Environ & life support systems trainers		x						
	Separation system trainer			x					Preliminary training for orbiter and booster can be given in common, particularly the parts involving principles of operation. Divergence occurs in the specific differences in application, size, location, interface, etc.
	MPS trainer			x					
	APU trainer		x						
	ABES trainer		x						
	ABES deployment trainer			x					
	Landing gear trainer			x					
	ACPS trainer			x					
	TVC trainer		x						
	Aero surface act. trainer			x					
	TPS trainer		x						
	Display & control trainer		x						
	DCM trainer		x						
	COFI trainer		x						
	GN&C trainer		x						
	Pyrotechnic device trainer		x						

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SPACE SHUTTLE COMMONALITY CANDIDATES

Subsystem Group: Training

Subsystem	Major Components	Commonality Category A	B	C	D	E	Development Responsibility (Contractor/Center) Orbiter/MSC	Booster/MSFC	Discussion
Training categories	Flight crew		x				TO BE DETERMINED DURING PHASE C/D NEGOTIATION		
	Manufacturing processes		x						
	On-the-job training		x						
	Certification training		x						
	Maintenance training		x						
	Safety training		x						
	Familiarization training			x					
	Operations and procedures		x						
Facilities	Training facilities at KSC		x						Training facilities such as classrooms, simulation and trainer areas, teaching aids such as projectors, TV, screens, etc., are common across the board.
	Training facilities at Michoud		x						

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